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ASTRONOMY

Chapter 29 THE BIG BANG

PowerPoint Image Slideshow

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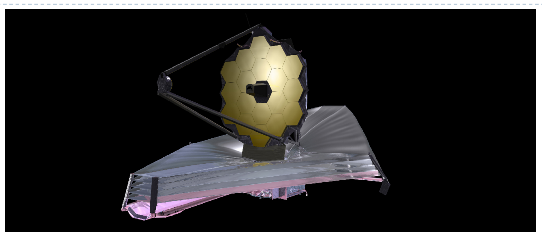
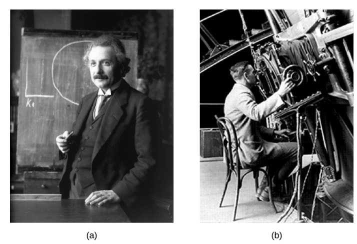
29.1 THE AGE OF THE UNIVERSE



- **Space Telescope of the Future.** This drawing shows the James Webb Space Telescope, which is currently planned for launch in 2018. The silver sunshade shadows the primary mirror and science instruments. The primary mirror is 6.5 meters (21 feet) in diameter. Before and during launch, the mirror will be folded up. After the telescope is placed in its orbit, ground controllers will command it to unfold the mirror petals. To see distant galaxies whose light has been shifted to long wavelengths, the telescope will carry several instruments for taking infrared images and spectra. (credit: modification of work by NASA)

Figure 29.2

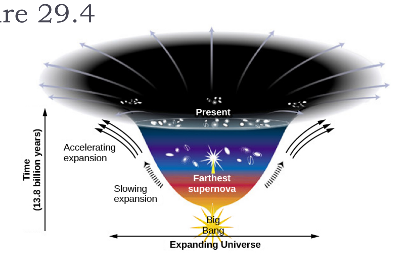


- **Einstein and Hubble.**
- (a) Albert Einstein is shown in a 1921 photograph.
- (b) Edwin Hubble at work in the Mt. Wilson Observatory.

Figure 29.3

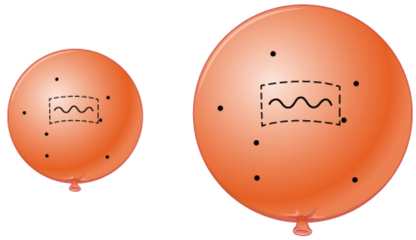
- **Five Supernovae and Their Host Galaxies.** The top row shows each galaxy and its supernova (arrow). The bottom row shows the same galaxies either before or after the supernovae exploded. (credit: modification of work by NASA, ESA, and A. Riess (STScI))

Figure 29.4



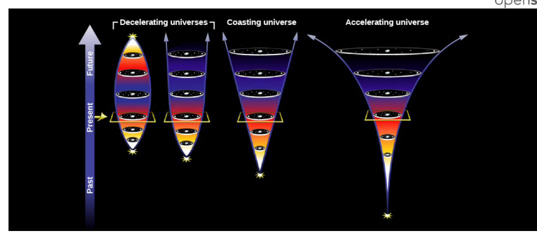
- **Changes in the Rate of Expansion of the Universe Since Its Beginning 13.8 Billion Years Ago.** The more the diagram spreads out horizontally, the faster the change in the velocity of expansion. After a period of very rapid expansion at the beginning, which scientists call inflation and which we will discuss later in this chapter, the expansion began to decelerate. Galaxies were then close together, and their mutual gravitational attraction slowed the expansion. After a few billion years, when galaxies were farther apart, the influence of gravity began to weaken. Dark energy then took over and caused the expansion to accelerate. (credit: modification of work by Ann Feild (STScI))

Figure 29.7

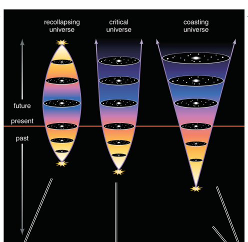


Expansion and Redshift. As an elastic surface expands, a wave on its surface stretches. For light waves, the increase in wavelength would be seen as a redshift.

Figure 29.8



Four Possible Models of the Universe. The yellow square marks the present in all four cases, and for all four, the Hubble constant is equal to the same value at the present time. Time is measured in the vertical direction. The first two universes on the left are ones in which the rate of expansion slows over time. The one on the left will eventually slow, come to a stop and reverse, ending up in a "big crunch," while the one next to it will continue to expand forever, but ever-more slowly as time passes. The "coasting" universe is one that expands at a constant rate given by the Hubble constant throughout all of cosmic time. The accelerating universe on the right will continue to expand faster and faster forever. (credit: modification of work by NASA/ESA)

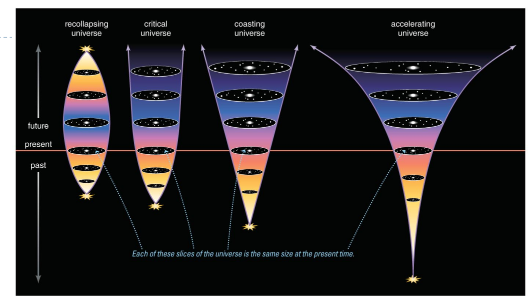


Fate of universe depends on the amount of dark matter.

Lots of dark matter

Critical density of matter

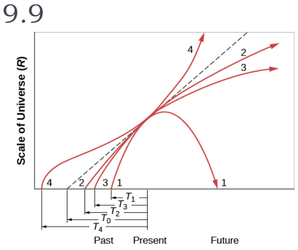
Not enough dark matter



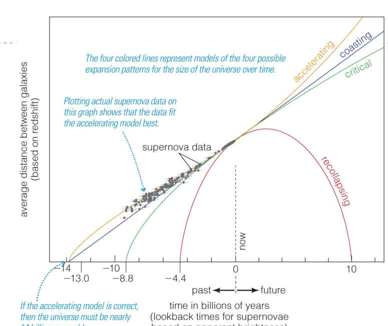
old older oldest

Estimated age depends on both dark matter and dark energy.

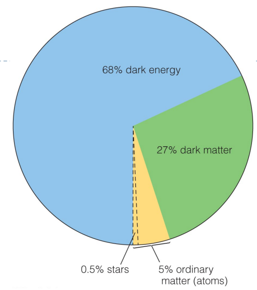
Figure 29.9



Models of the Universe. This graph plots *R*, the scale of the universe, against time for various cosmological models. Curve 1 represents a universe where the density is greater than the critical value; this model predicts that the universe will eventually collapse. Curve 2 represents a universe with a density lower than critical; the universe will continue to expand but at an ever-slower rate. Curve 3 is a critical-density universe; in this universe, the expansion will gradually slow to a stop infinitely far in the future. Curve 4 represents a universe that is accelerating because of the effects of dark energy. The dashed line is for an empty universe, one in which the expansion is not slowed by gravity or accelerated by dark energy. Time is very compressed on this graph.

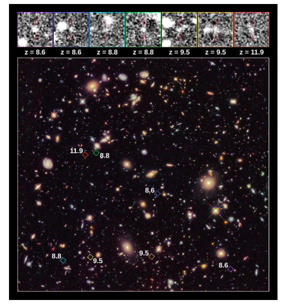


An accelerating universe is the best fit to supernova data.



Observations tell us that the density of the universe is equal to the critical density, but we can only account for 30% of that with matter!

Figure 29.10



Hubble Ultra-Deep Field. This image, called the Hubble Ultra Deep Field, shows faint galaxies, seen very far away and therefore very far back in time. The colored squares in the main image outline the locations of the galaxies. Enlarged views of each galaxy are shown in the black-and-white images. The red lines mark each galaxy's location. The "redshift" of each galaxy is indicated below each box, denoted by the symbol "z." The redshift measures how much a galaxy's ultraviolet and visible light has been stretched to infrared wavelengths by the universe's expansion. The larger the redshift, the more distant the galaxy, and therefore the further astronomers are seeing back in time. One of the seven galaxies may be a distance breaker, observed at a redshift of 11.9. If this redshift is confirmed by additional measurements, the galaxy is seen as it appeared only 380 million years after the Big Bang, when the universe was less than 3% of its present age. (credit: modification of work by NASA, ESA, R. Ellis (Caltech), and the UDF 2012 Team)

29.3 THE BEGINNING OF THE UNIVERSE

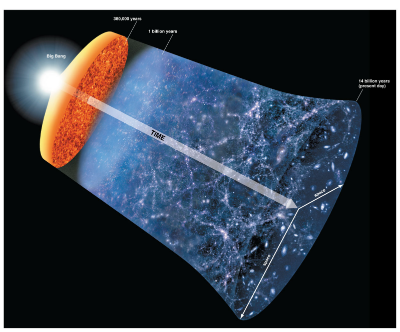
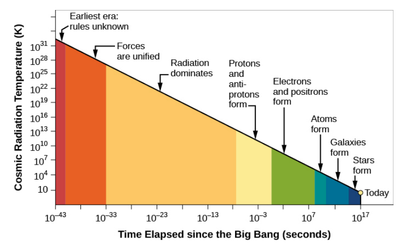
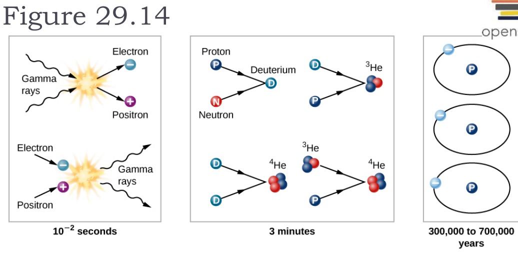


Figure 29.13



Temperature of the Universe. This graph shows how the temperature of the universe varies with time as predicted by the standard model of the Big Bang. Note that both the temperature (vertical axis) and the time in seconds (horizontal axis) change over vast scales on this compressed diagram.

Figure 29.14



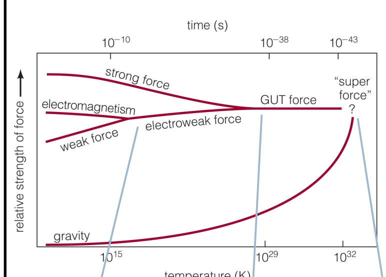
Particle Interactions in the Early Universe.

(a) In the first fractions of a second, when the universe was very hot, energy was converted into particles and antiparticles. The reverse reaction also happened: a particle and antiparticle could collide and produce energy.

(b) As the temperature of the universe decreased, the energy of typical photons became too low to create matter. Instead, existing particles fused to create such nuclei as deuterium and helium.

(c) Later, it became cool enough for electrons to settle down with nuclei and make neutral atoms. Most of the universe was still hydrogen.

Do forces unify at high temperatures?



Four known forces in universe:

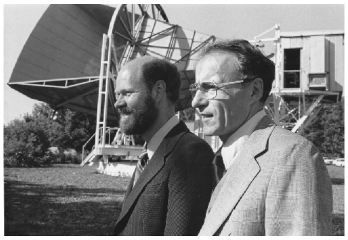
Strong Force
Electromagnetism
Weak Force
Gravity

Yes! (Electroweak)

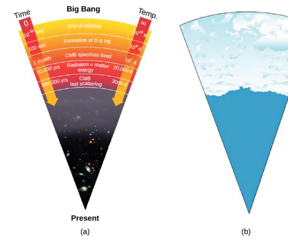
Maybe (GUT)

Who knows? (String Theory)

29.4 THE COSMIC MICROWAVE BACKGROUND



- **Robert Wilson (left) and Arno Penzias (right).** These two scientists are standing in front of the horn-shaped antenna with which they discovered the cosmic background radiation. The photo was taken in 1978, just after they received the Nobel Prize in physics.

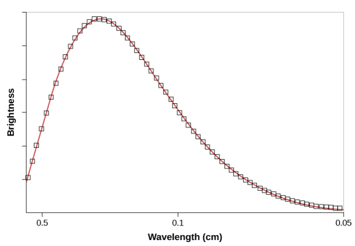


- **Cosmic Microwave Background and Clouds Compared.**

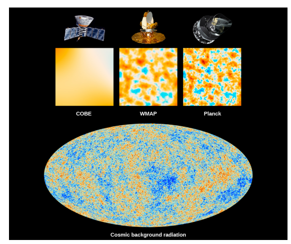
(a) Early in the universe, photons (electromagnetic energy) were scattering off the crowded, hot, charged particles and could not get very far without colliding with another particle. But after electrons and photons settled into neutral atoms, there was far less scattering, and photons could travel over vast distances. The universe became transparent. As we look out in space and back in time, we can't see back beyond this time.

(b) This is similar to what happens when we see clouds in Earth's atmosphere. Water droplets in a cloud scatter light very efficiently, but clear air lets light travel over long distances. So as we look up into the atmosphere, our vision is blocked by the cloud layers and we can't see beyond them. (credit: modification of work by NASA)

Figure 29.17

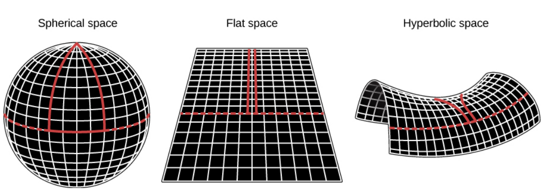


- **Cosmic Background Radiation.** The solid line shows how the intensity of radiation should change with wavelength for a blackbody with a temperature of 2.73 K. The boxes show the intensity of the cosmic background radiation as measured at various wavelengths by COBE's instruments. The fit is perfect. When this graph was first shown at a meeting of astronomers, they gave it a standing ovation.

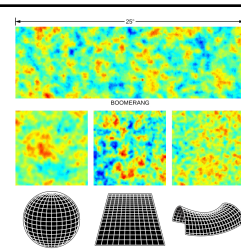


- **CMB Observations.** This comparison shows how much detail can be seen in the observations of three satellites used to measure the CMB. The CMB is a snapshot of the oldest light in our universe, imprinted on the sky when the universe was just about 380,000 years old. The first spacecraft, launched in 1989, is NASA's Cosmic Background Explorer, or COBE. WMAP was launched in 2001, and Planck was launched in 2009. The three panels show 10-square-degree patches of all-sky maps. This cosmic background radiation image (bottom) is an all-sky map of the CMB as observed by the Planck mission. The colors in the map represent different temperatures: red for warmer and blue for cooler. These tiny temperature fluctuations correspond to regions of slightly different densities, representing the seeds of all future structures: the stars, galaxies, and galaxy clusters of today.

Figure 29.19



- The overall geometry of the universe is closely related to total density of matter and energy.



- **Comparison of CMB Observations with Possible Models of the Universe.** Cosmological simulations predict that if our universe has critical density, then the CMB images will be dominated by hot and cold spots of around one degree in size (bottom center). If, on the other hand, the density is higher than critical (and the universe will ultimately collapse), then the images' hot and cold spots will appear larger than one degree (bottom left). If the density of the universe is less than critical (and the expansion will continue forever), then the structures will appear smaller (bottom right). As the measurements show, the universe is at critical density. The measurements shown were made by a balloon-borne instrument called BOOMERanG (Balloon Observations of Millimetric Extragalactic Radiation and Geophysics), which was flown in Antarctica. Subsequent satellite observations by WMAP and Planck confirm the BOOMERanG result.

29.5 WHAT IS THE UNIVERSE REALLY MADE OF?

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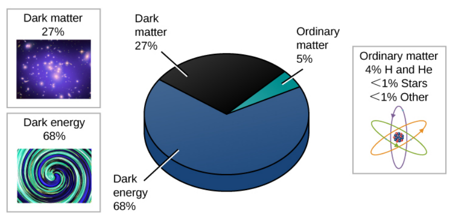

- **Composition of the Universe.** Only about 5% of all the mass and energy in the universe is matter with which we are familiar here on Earth. Most ordinary matter consists of hydrogen and helium located in interstellar and intergalactic space. Only about one-half of 1% of the critical density of the universe is found in stars. Dark matter and dark energy, which have not yet been detected in earthbound laboratories, account for 95% of the contents of the universe.

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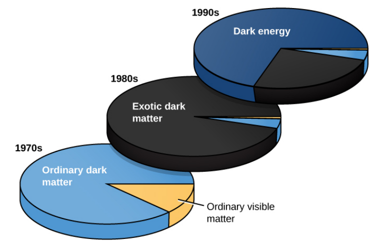
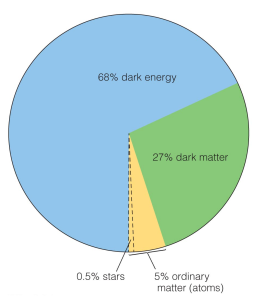


- **Changing Estimates of the Content of the Universe.** This diagram shows the changes in our understanding of the contents of the universe over the past three decades. In the 1970s, we suspected that most of the matter in the universe was invisible, but we thought that this matter might be ordinary matter (protons, neutrons, etc.) that was simply not producing electromagnetic radiation. By the 1980s, it was becoming likely that most of the dark matter was made of something we had not yet detected on Earth. By the late 1990s, a variety of experiments had shown that we live in a critical -density universe and that dark energy contributes about 70% of what is required to reach critical density. Note how the estimate of the relative importance of ordinary luminous matter (shown in yellow) has diminished over time.



Two Basic Options

- Ordinary Matter (MACHOs)
  - Massive Compact Halo Objects: dead or failed stars in halos of galaxies
- Exotic Particles (WIMPs)
  - Weakly Interacting Massive Particles: mysterious neutrino-like particles

Figure 29.23

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- **Dark Matter.** This cartoon from NASA takes a humorous look at how little we yet understand about dark matter. (credit: NASA)

29.6 THE INFLATIONARY UNIVERSE

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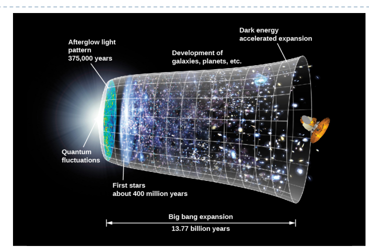
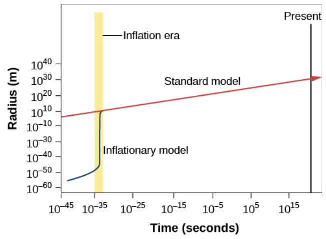


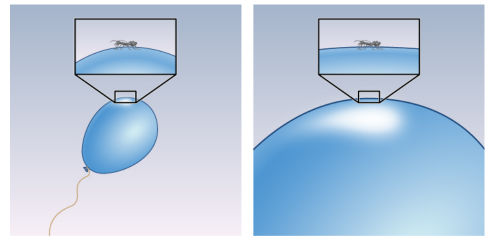
- **History of the Universe.** This image summarizes the changes that have occurred in the universe during the last 13.8 billion years. Protons, deuterium, helium, and some lithium were produced in the initial fireball. About 380,000 years after the Big Bang, the universe became transparent to electromagnetic radiation for the first time.

Figure 29.25



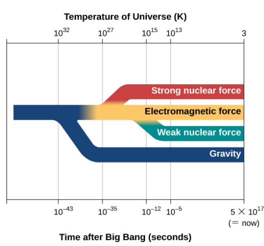
- **Expansion of the Universe.** This graph shows how the scale factor of the observable universe changes with time for the standard Big Bang model (red line) and for the inflationary model (blue line). (Note that the time scale at the bottom is extremely compressed.) During inflation, regions that were very small and in contact with each other are suddenly blown up to be much larger and outside each other's horizon distance. The two models are the same for all times after 10–30 second.

Figure 29.26

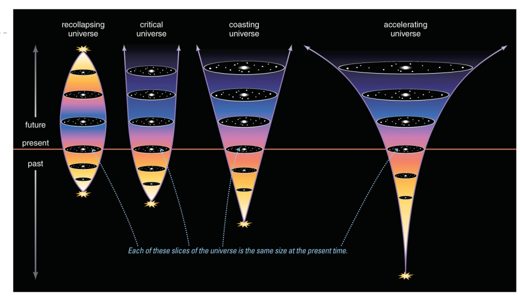


- **Analogy for Inflation.** During a period of rapid inflation, a curved balloon grows so large that to any local observer it looks flat. The inset shows the geometry from the ant's point of view.

Figure 29.27



- **Four Forces That Govern the Universe.** The behavior of the four forces depends on the temperature of the universe. This diagram (inspired by some grand unified theories) shows that at very early times when the temperature of the universe was very high, all four forces resembled one another and were indistinguishable. As the universe cooled, the forces took on separate and distinctive characteristics.



We expect that the universe will continue expanding forever, as dark energy continues to accelerate the expansion!

Links

- dark energy 4
- curvature 5

Reading

- 29.1 optional
- 29.2
- 29.3 optional
- 29.4
- 29.5
- 29.6
- 29.7 omit