

**Cosmic Chemistry: Cosmogony**

**Selected Noteworthy Events in Cosmology**

**APPENDIX C**

- 1576..... Thomas Diggs in England publishes a defense of the Copernican cosmology in which he portrays the stars as distributed throughout infinite space.
- 1604..... Galileo proposes that bodies fall with a uniformly accelerated motion—first of laws of classical dynamics.
- 1665-66..... Isaac Newton (23 years old) realizes that gravitational force obeying an inverse-square law would account alike for falling bodies on earth and the motion of the moon in its orbit.
- 1687..... Newton's *Principia* published.
- 1750-1784.. French amateur astronomer Charles Messier catalogs scores of indistinct celestial objects that might be mistaken for comets; many will prove to be star clusters and interstellar gas clouds; other external galaxies
- 1755..... Kent proposes that spiral nebulae are galaxies of stars.
- 1766..... Henry Cavendish identifies hydrogen, the most abundant element in the universe.
- 1842..... Christian Johann Doppler defines Doppler effect—the wavelength of sound or other emissions from a moving source will appear to a stationary observer to be higher in frequency if the object is approaching, lower if it is receding.
- 1845..... Lord Rosse constructs a 72-inch reflecting telescope.
- 1864..... William Huggins obtains the first spectrum of a nebula, finds that it is composed of gas.
- 1879..... Albert Michelson uses Foucault's principle to determine the velocity of light.
- 1895..... E. E. Barnard photographs the Milky Way, notes that dark patches are too numerous to be empty space but must represent dark clouds of interstellar matter.
- 1888..... Dreyer publishes *New General Catalog*, the result of telescopic searches of William and John Herschel; included distribution of spiral galaxies.
- 1899..... Julius Scheiner obtains a spectrum of the nucleus of a giant spiral in Andromeda using a combination of a tracking telescope and photographic recording.
- 1905..... Albert Einstein publishes special theory of relativity—measurements of time and space are distorted at high velocity, implying that mass and energy are equivalent; in another paper he shows that light is composed of quanta—photons.
- 1913..... Neils Bohr develops theory of atomic structure in which electrons orbit the nucleus in a manner similar to that of planets orbiting the sun.
- 1914..... Walter Adams and Arnold Kholshutter determine the absolute luminosity of stars from their spectra alone, making it possible to estimate the distances of millions of distant stars.
- 1916..... Albert Einstein publishes general theory of relativity, portraying gravitation as an effect of curved space and delivering cosmology from the ancient dilemma of a finite versus an infinite structure.
- 1917..... Vesto Slipher measures the large Doppler shifts in the spectra of spiral galaxies, later found to be due to their motion in the expanding universe.
- 1918..... Harlow Shapley determines, by studying the distances of globular clusters, that the sun lies toward one edge of a galaxy of stars.  
..... The 100-inch telescope at Mount Wilson begins operation.
- 1922..... Ernst Opik deduces, from rotation velocities and the mass to luminosity ratio of the Andromeda spiral, that it is a galaxy in its own right.
- 1925..... Bertil Lindblad demonstrates that the motion of stars called "star streaming" by Kapteyn in 1905 can be explained as being due to the rotation of the Milky Way galaxy.  
..... Edwin Hubble announces that he has identified Cepheid variable stars in the Andromeda galaxy, confirming that it is a galaxy of stars rather than a gaseous nebula.
- 1927..... Jan Oort detects evidence of the rotation of the Milky Way galaxy, by examining the radial velocities of stars.
- 1929..... Edwin Hubble announces a relationship between the redshift in the spectra of galaxies and their distances, indicating that the universe is expanding.
- 1930..... Robert Trumpler's studies of open star clusters enable him to measure the extent to which interstellar clouds dim and redden starlight, greatly improving estimates of the distances of stars.
- 1932..... Karl Jansky finds that the Milky Way emits radio waves, initiating the science of radio astronomy.



- 1933..... Fritz Zwicky discovers that outlying galaxies in the Coma cluster are moving much faster than they would be if its mass were limited to that of the visible galaxies in it. Zwicky calculates that Coma is more than 0.9 dark matter.
- 1940..... Grote Reber constructs a backyard radio telescope, makes the first radio map of the Milky Way.
- 1943..... Carl Seyfert identifies Seyfert galaxies, the first of a larger class of galaxies found to have bright nuclei that emit abnormal amounts of energy.
- 1944..... Walter Baade resolves the central region of the Andromeda galaxy into stars, establishing a fundamental distinction between the older, redder stars characteristic of the centers of spiral galaxies, and the younger, bluer stars found in their spiral arms.
- 1945..... Hendrik van de Hulst predicts that clouds of interstellar hydrogen emit radio energy of 21-cm wavelength.
- 1946..... James Hey, S. J. Parsons, and J. W. Phillips identify a powerful radio source in Cygnus, initiating research that leads to finding galaxies that emit enormous amounts of energy at radio wavelengths.
- 1948..... Dedication of the 200-inch telescope on Palomar Mountain.
- 1949..... John Bolton, Gordon Stanley, and O. B. Slee use radio interferometry to identify three radio sources with visible objects; two of them are galaxies, suggesting that what had been thought to be radio “stars” are actually objects lying much farther away in space.
- 1950..... Jan Oort studies orbital velocity of stars near the sun.  
..... Vera Rubin finds the supergalactic plane, the observation that local galaxies are being pulled in the direction of Pegasus, now called the Rubin-Ford effect. [Her paper, “Rotation of the Universe,” was rejected by both the *Astrophysical Journal* and the *Astronomical Journal*. After considerable discussion, she was allowed to present it at an AAS meeting in December, 1950.]
- 1951..... Harold Ewen and Edward Purcell, closely followed by C. Alex Muller and Jan Oort, detect 21-cm radio radiation emitted by interstellar clouds.
- 1954..... Walter Baade and Rudolph Minkowski identify the radio source Cygnus A in a distant galaxy.
- 1958..... Jan Oort and colleagues use radio telescopes to map the spiral arms of the Milky Way galaxy.  
..... First serious study of clusters done by George Abell, working from photographic plates.
- 1959..... Solar “wind” is discovered early in the 1960s by automated spacecraft Lunik II and Lunik III on their way toward the moon.
- 1960's..... Allan Sandage and Thomas Matthews discover quasars.
- 1962..... Using an image-tube electronic enhancer spectrograph built by Kent Ford, Vera Rubin examines kinematics of 888 early type stars in our Galaxy; concludes that beyond the sun the decrease in rotational velocity is not found.
- 1963..... Maarten Schmidt finds redshift in the spectral lines of a quasar, indicating that quasars are the most distant class of objects in the universe.
- 1964..... Gerard and A. de Valcouleurs publishes a *Reference Catalog of Bright Galaxies*, followed by a second catalog in 1976.  
..... Murray Gell-Mann, Caltech, proposes that protons and neutrons are composed of three particles, which he called quarks.
- 1966..... Scientists working at Stanford Linear Accelerator Center use energetic electrons to show that protons and neutrons are composed of smaller particles.
- 1967..... Chia Lin and Frank Shu show that the spiral arms of galaxies may be created by density waves propagating across the galactic disk.  
..... Jocelyn Bell and Antony Hewish discover pulsars, leading to verification of the existence of pulsars.  
..... Donald Shane and Carl Wirtanen, Lick Observatory, publish a catalogue of locations of a million galaxies, working with the unaided eye and examining thousands of photographic plates; P. J. E. Peebles and his co-workers at Princeton use the Shane-Wirtanen survey to put together the first visualization (map) of the universe
- 1970's..... Several major redshift surveys identify long, string-like structures, now called superclusters.
- 1970..... Experimenters at CERN research center use neutrinos to assault protons with results that support the quark hypothesis.
- 1981..... Astronomers from University of Michigan discover the first void in the constellation Boötes.
- 1982..... Basertano, Bahcall, Caldwell and Ostriker construct multicomponent mass distributions, consisting of central point masses, disks, bulges, and halos, based on observed rotational properties of spiral galaxies.
- 1985..... Astronomers at Harvard-Smithsonian Center for Astrophysics find the universe was full of large bubbles.
- 1988..... Quasars are detected near the outposts of the observable universe, their redshifts indicate that their light has been traveling through space for some 17 billion years.



- 1989..... NASA's Cosmic Background Explorer (COBE) project gathers spectral data on the cosmic microwave background (CMB) radiation above Earth's atmosphere from its orbiting spacecraft.
- 1994-95..... Observations with Keck telescope are used to infer deuterium abundance in early universe.
- 1995..... Space shuttle astronauts use ultraviolet telescope to detect helium in intergalactic clouds 10 billion light-years away.  
..... Scientists at Fermilab in Batavia, IL, identify top quark.
- 2000..... Free quarks and gluons are produced in CERN particle physics laboratory.

---

\* taken from the following references and other references listed in the References, Resources, URL's and CD ROMs:

1. *Coming of Age in the Milky Way*, Timothy Ferris, William Morris and Company, Inc., New York, 1988.
2. *Bright Galaxies, Dark Matters*, Vera Rubin, American Institute of Physics Press, Woodbury, NY, 1997.