CLOSE BINARY EVOLUTION LEADING TO TYPE Ia SUPERNOVA EXPLOSION A ITS IMPACT ON COSMOLOGY

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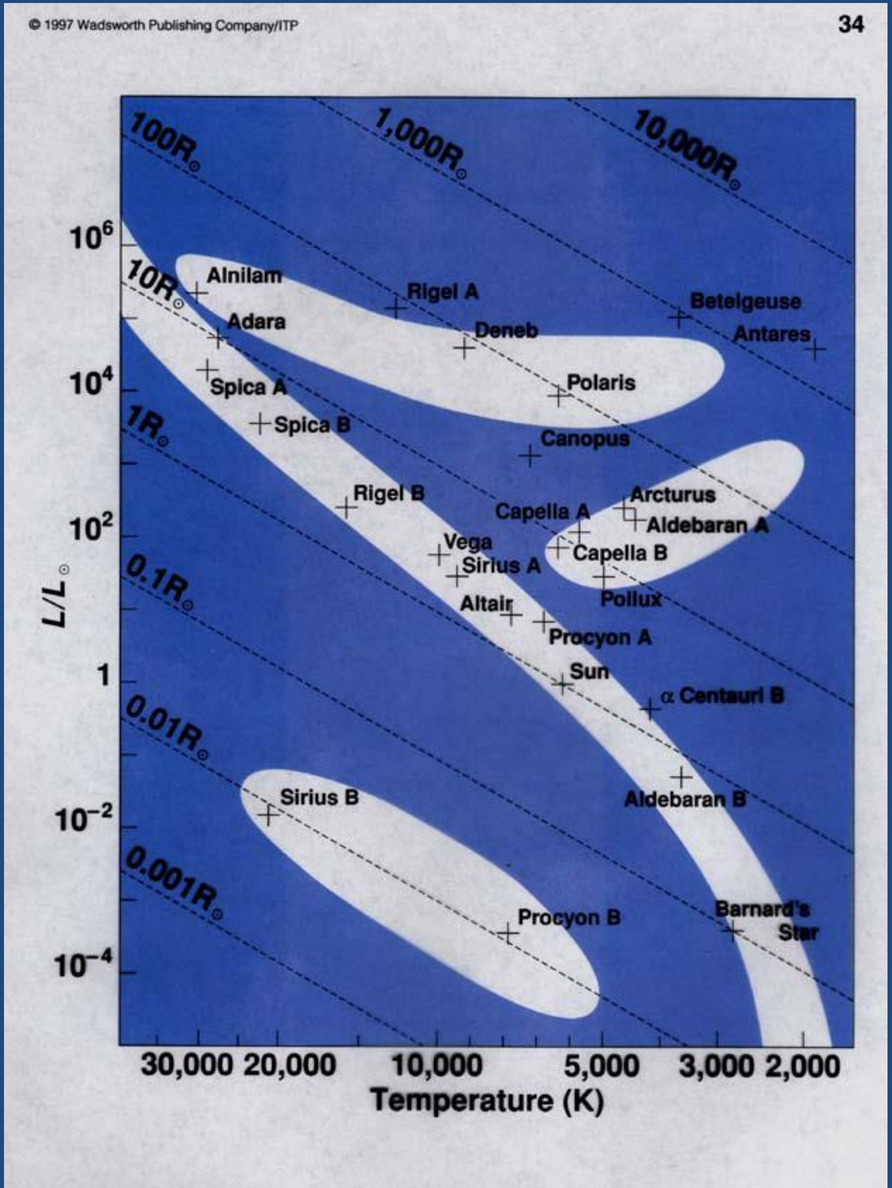
H-R Diagram

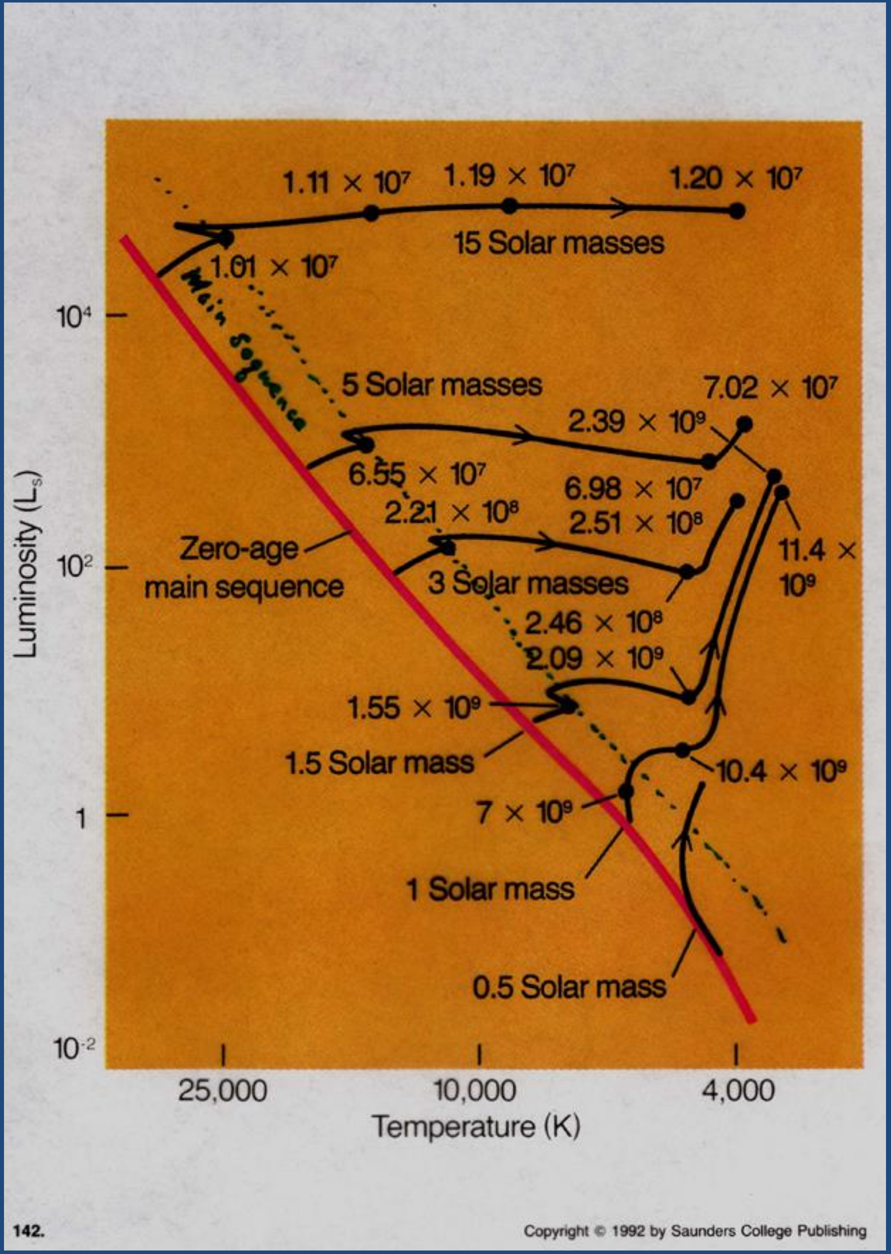


H–R diagram: lines of constant radius

EVOLUTION OF SINGLE STAR

- Initially the chemical composition of the energy producing core and the envelope are the same, about ¾ H and 1/3 He.
- Nuclear fusion takes place at the core and/or at the shell around the core. Tcore = central temperature
- Tcore ~10 mk H → He
- Tcore ~100 mk He → Li → Be → B → …. C (carbon)
- Tcore ~600 mk C → N → O → ….. → Fe (iron)
- Stellar evolutionary model shows that as a star ages (t↑),
  t↑, Hcore↓ , Hecore↑, Rcore↓ , Tcore ↑ , Rstar ↑.
- That is a star expands as it ages.

Stellar Evolutionary Models



Nuclear Fusion In Stellar Interior, Hydrogen

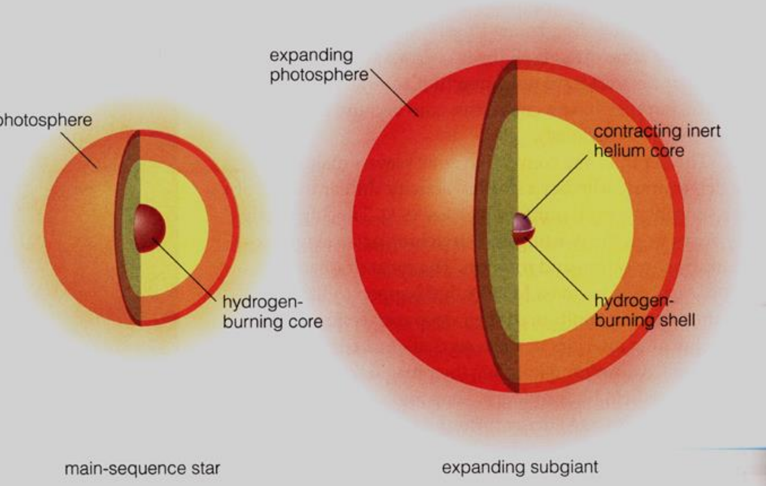


Figure 17.10 After a star ends its main-sequence life, its inert helium core contracts while hydrogen shell burning begins. The high rate of fusion in the hydrogen shell forces the star's upper layers to expand outward.

Nuclear Fusion In Stellar Interior, Helium

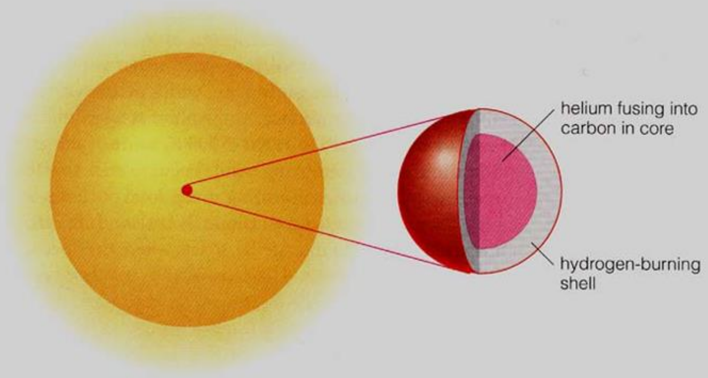


Figure 17.11 Core structure of a helium-burning star. Helium fusion causes the core and hydrogen-burning shell to expand and slightly cool, thereby reducing the overall energy generation rate in comparison to the rate during the red giant stage. The outer layers shrink back, so a helium-burning star is smaller than a red giant of the same mass.

Core Of Evolved Massive Star

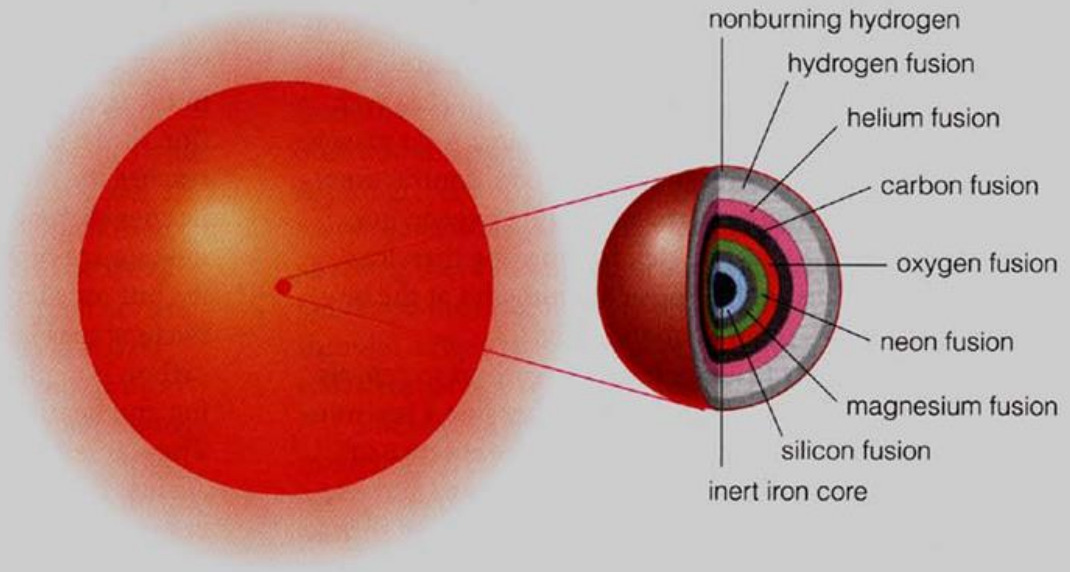


Figure 17.18 The multiple layers of nuclear burning in the core of a high-mass star during the final days of its life.

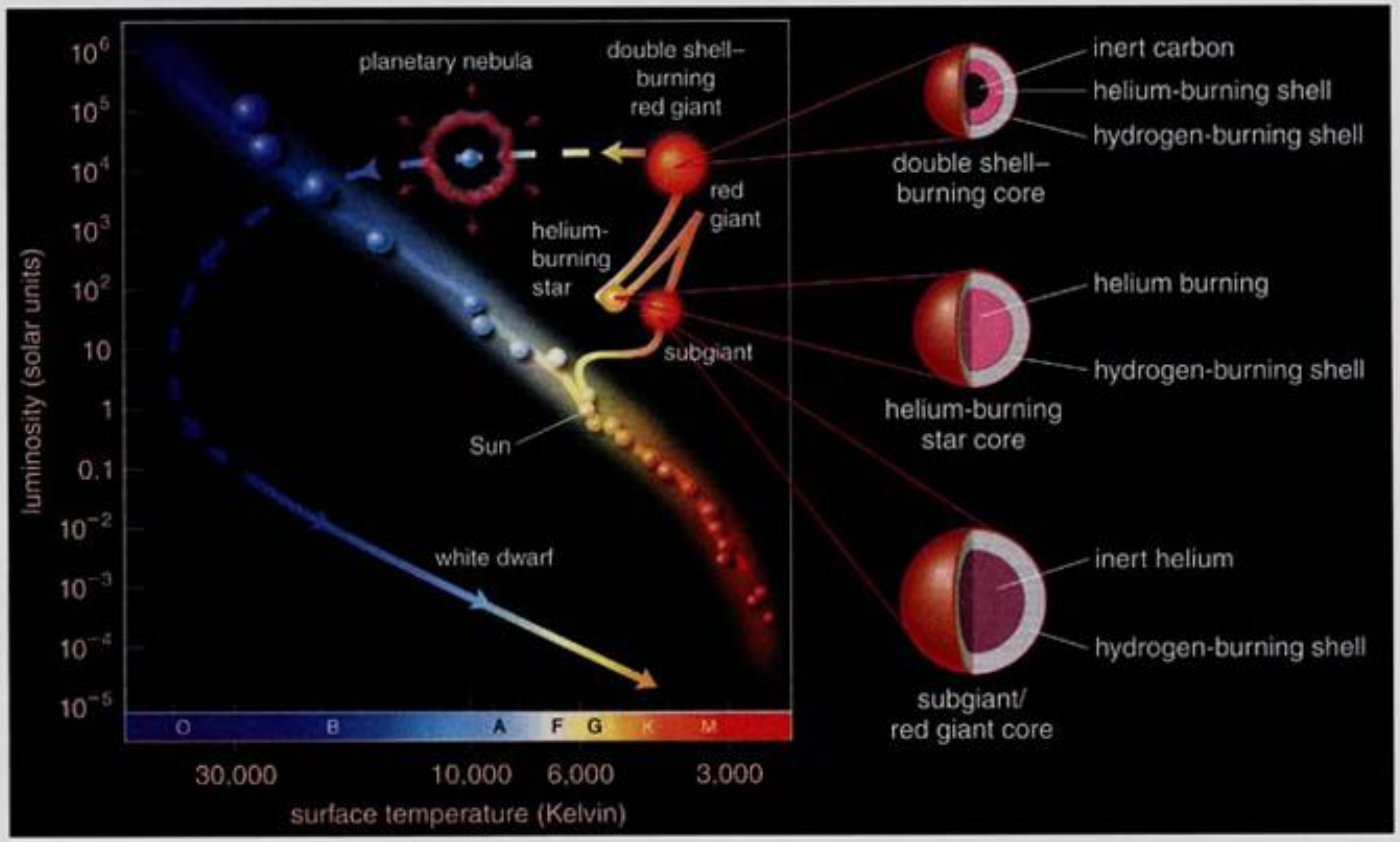
Death Of Single Stars

Initial Mass (mo)	Final State at end of its life
<0.01	Planet
0.01 to 0.08	Brown dwarf
0.08 to 0.25	White dwarf made mostly of helium
0.25 to 8-10	White dwarf made mostly of carbon and oxygen
8-10 to 12	White dwarf made of oxygen-neon-magnesium
12-40	Supernova explosion that leaves a neutron star
>40	Supernova explosion that leaves a black hole

Property	White Dwarf	Neutron Star
Mass limit	<1.4 mo	>1.4 mo
For Mass 1.0 mo		
Radius	5000 km	10 km
Density	5x105 g/cm3	1014 g/cm3

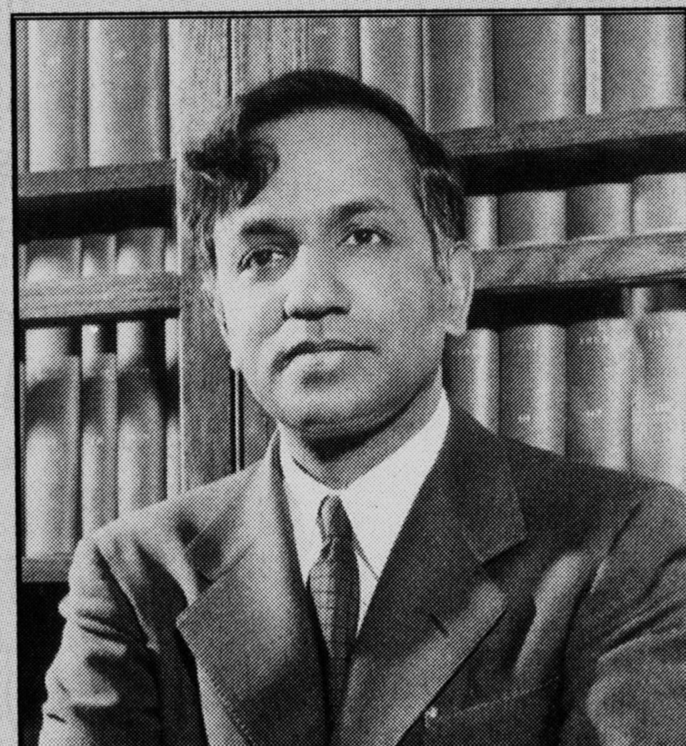
Formation Of White Dwarf

Figure 17.13 The life track of a $1M_{Sun}$ star from main-sequence star to white dwarf. Core structure is shown at key stages.



Chandrasekhar Limit

Subrahmanyan Chandrasekhar



S. Chandrasekhar (1910–1995) *(Courtesy of Emilio Segrè Visual Archives, Physics Today Collection)*

Roche Equipotential Surfaces In Close Binary System

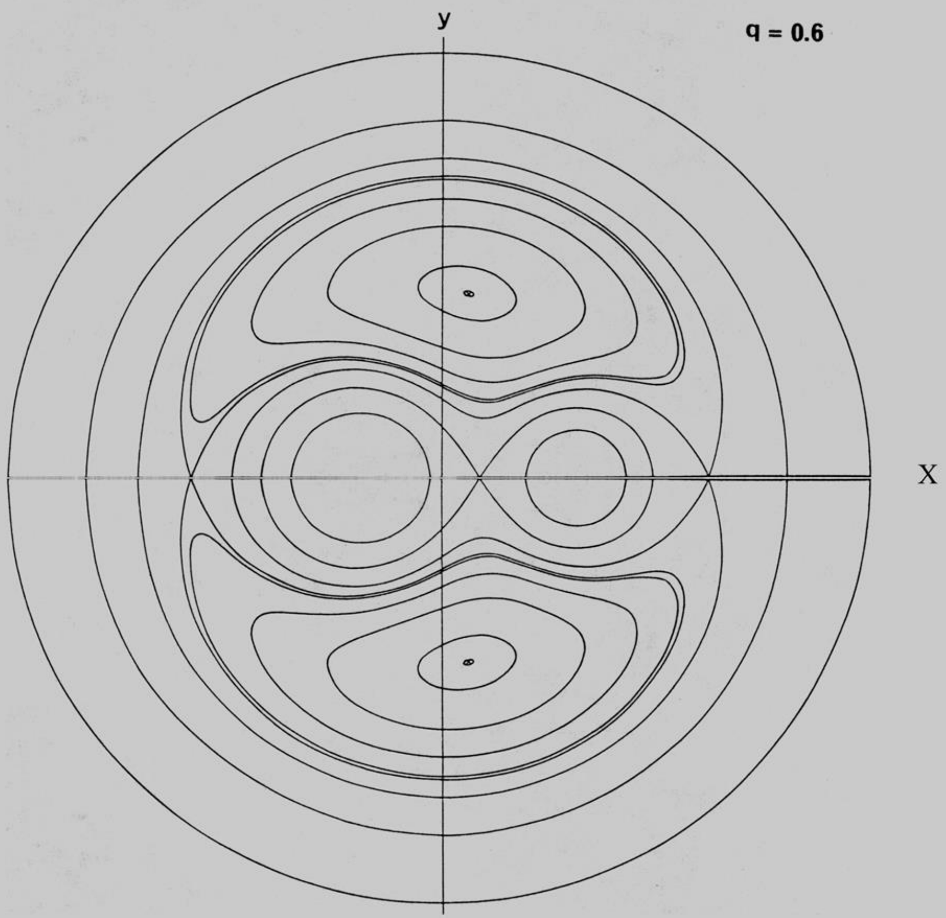
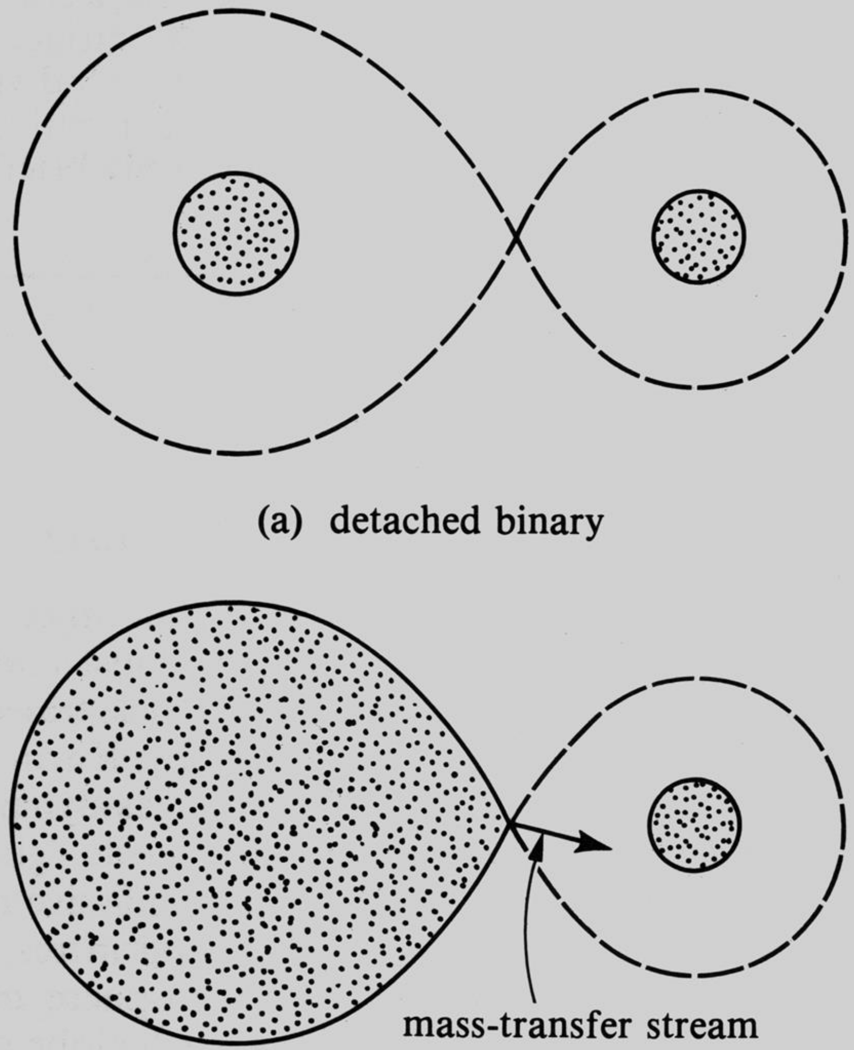


Fig. 6-5. Cross-sections of a family of the Roche equipotentials ξ = constant with the xy-plane for $y \geqslant 0$, corresponding to 10 different values of the potential, and the mass-ratio $q = 0.6$ (after Kopal, 1959).

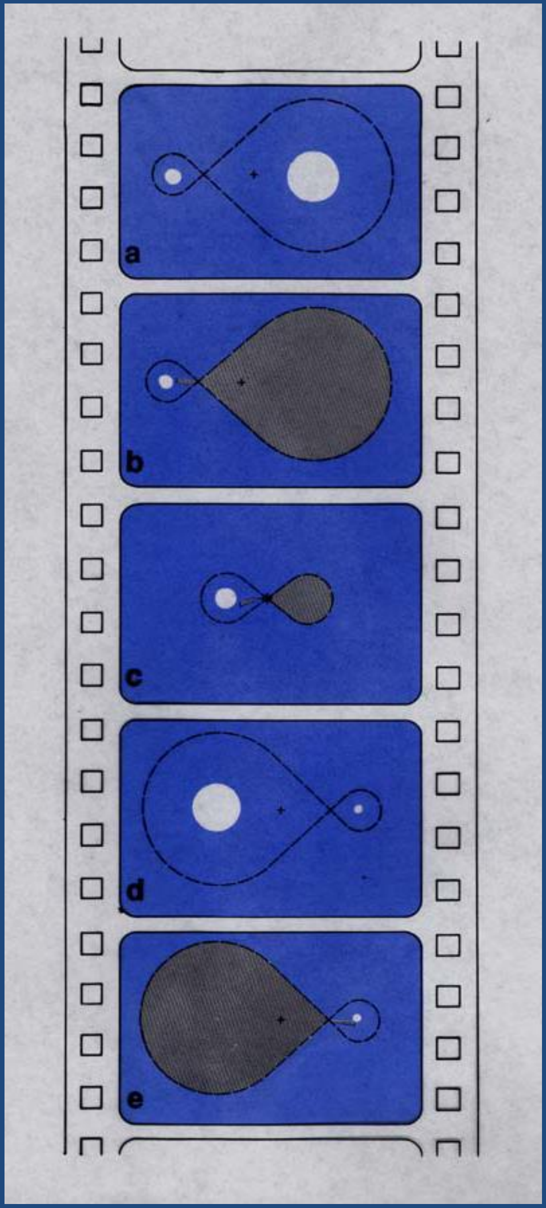
Mass-Transfer In Close Binary System



(a) detached binary

(b) semidetached binary

Mass Reversal In Binary System



Type Ia Supernova Explosion

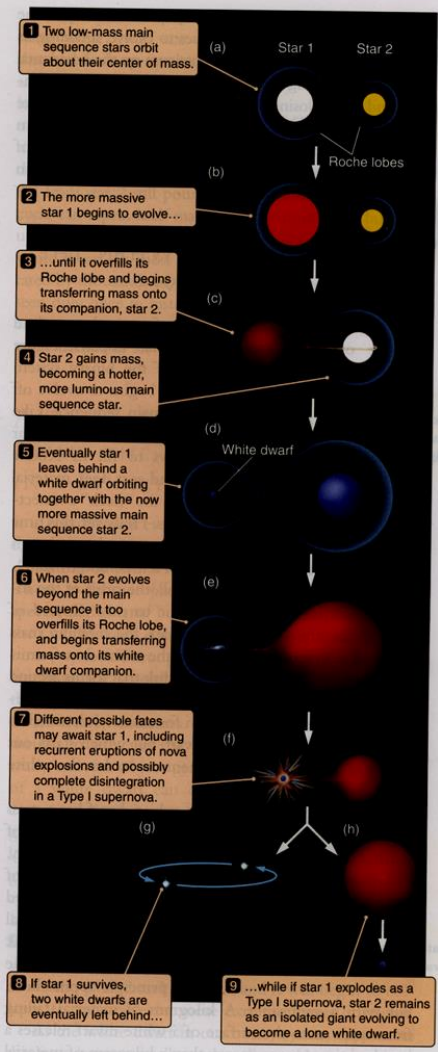


Figure 15.14 *A close binary system consisting of two low-mass stars passes through a sequence of stages as the stars evolve and mass is transferred back and forth. The evolution of the binary system can lead to novae or even to a Type I supernova that destroys the initially more massive star 1.*

White Dwarf Detonation

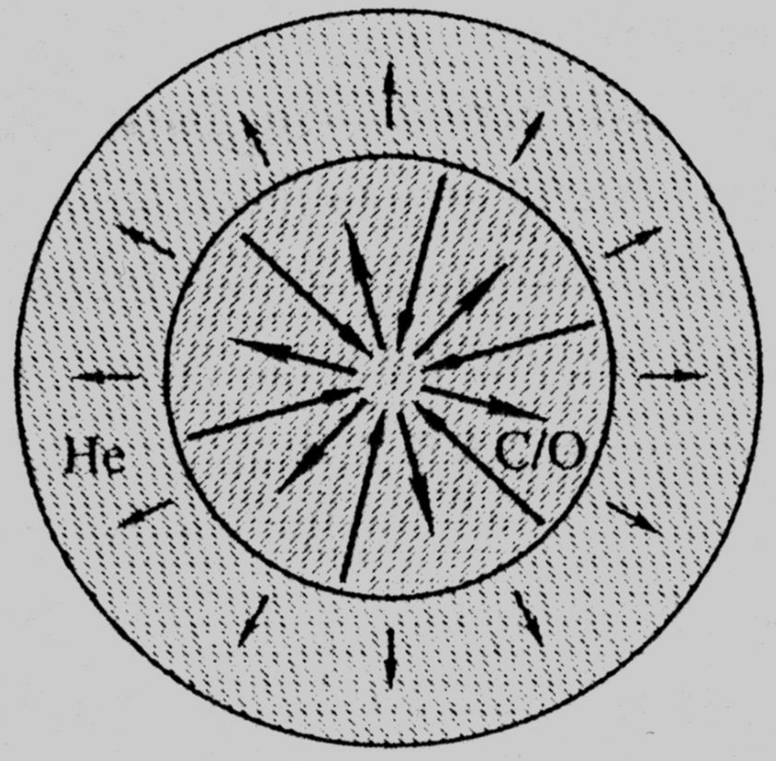


Figure 1. A schematic diagram of an edge-lit detonation (ELD). A degenerate CO white dwarf accretes a degenerate layer of He-rich material. When the base of this layer reaches a sufficiently high temperature the triple-α reaction ignites explosively. The shock of this explosion sets off explosive carbon burning in the CO core. Most of both the CO mixture and the helium shell are burnt to ^{56}Ni, while the high fraction of He nuclei in the outer layer leads to an α-rich freezeout creating such nuclei as ^{44}Ti.

Types of Supernova Explosion

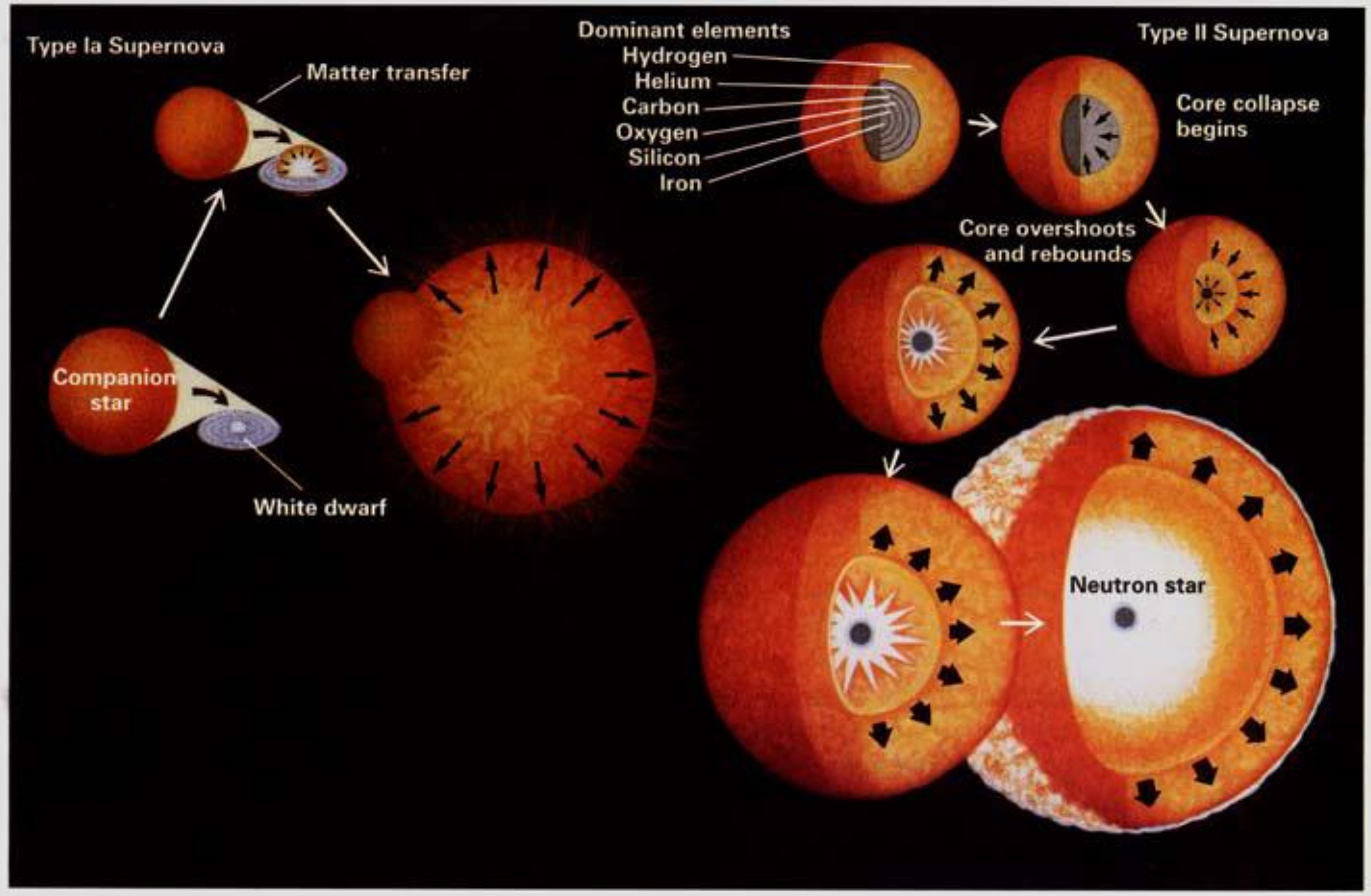


FIGURE 29–8 Type Ia supernovae (*left*) come from the incineration of a white dwarf that is accreting matter from a neighboring giant. Type II supernovae (*right*) are the explosions of massive stars, usually from the supergiant phase. When iron forms at the center of the onion-like layers of heavy elements, the star collapses. In this model of the collapse, the core over-shoots its final density and rebounds. The shock wave that results blasts off the star's outer layers.

The Difference In Light Curves

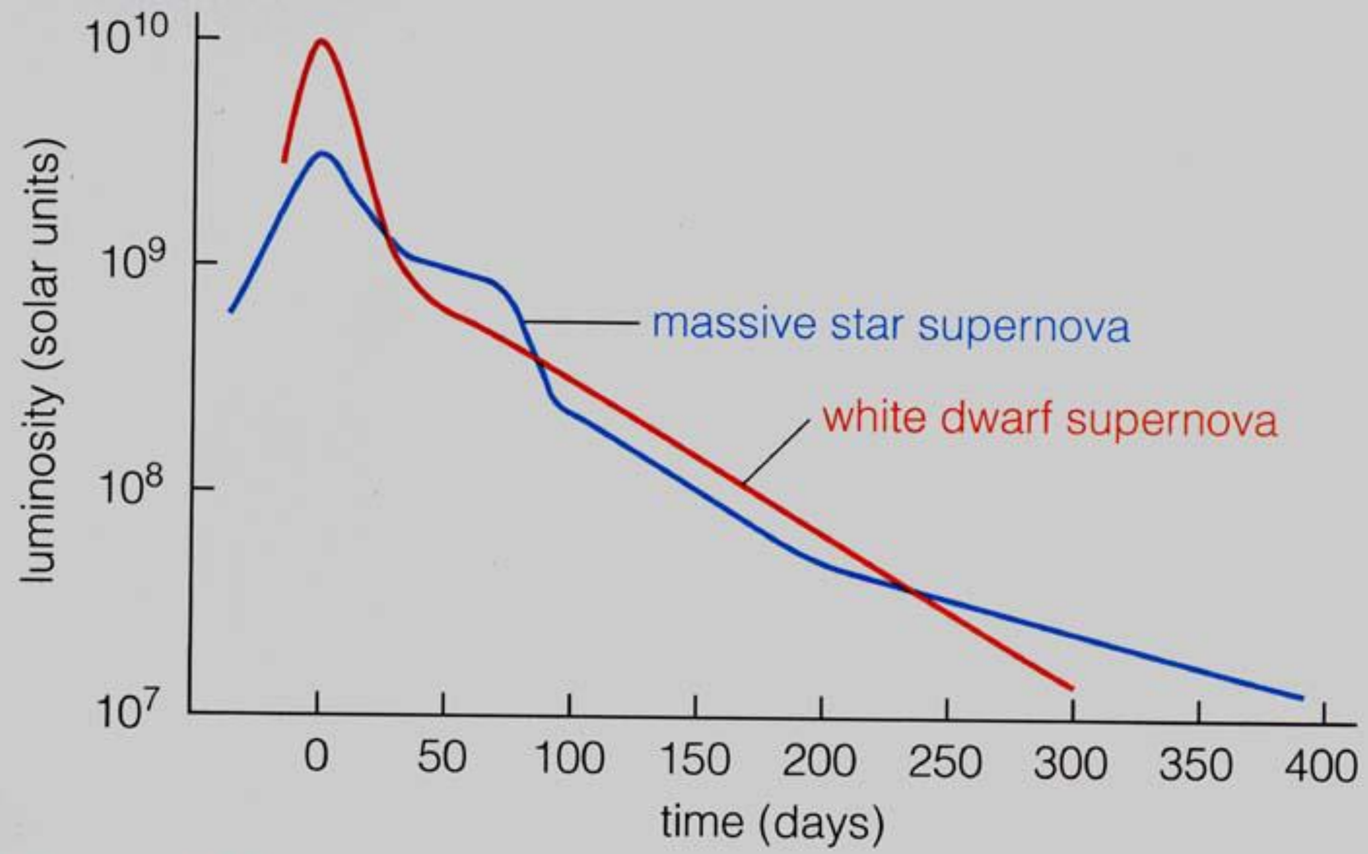


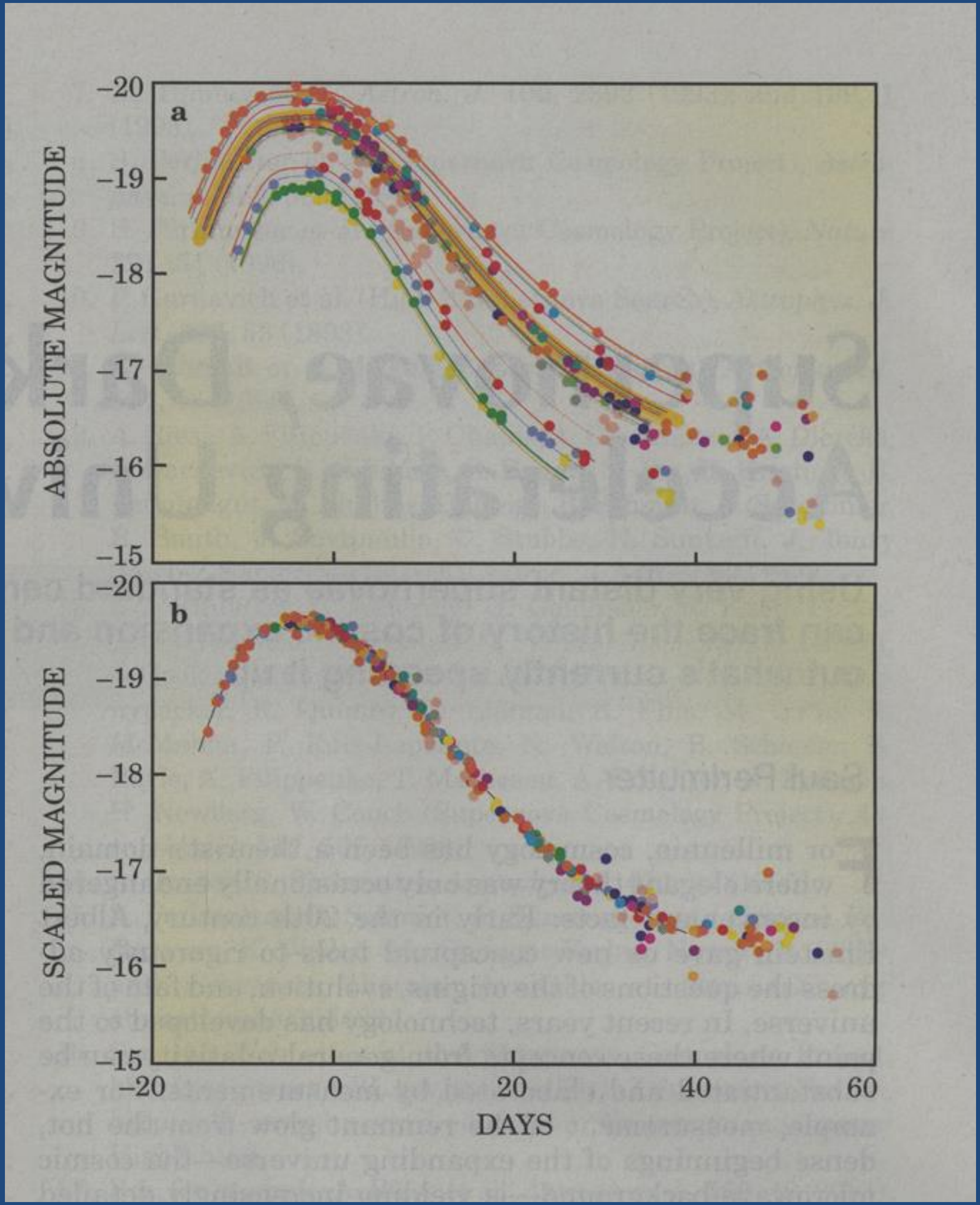
Figure 18.5 Typical light curves for white dwarf and massive star supernovae.

Spectroscopic Differences

TYPES OF SUPERNOVAE

	Type Ia	Type II
Source	White dwarf in Binary	Massive star
Spectrum	No hydrogen lines	Hydrogen lines
Peak	Sharp 1.5 mag brighter type II	Broader when graphed vs time
Light curve	All have same Mbol Rapid rise, Decay with several-weeks Half-life	Different mag
Location	All types of galaxy	Spiral only
Expansion	10,000 km/sec	5,000 km/sec
Radio radiation	Absent	Present
Hydrogen	No Hydrogen lines	H Balmer spectrum

Standard Light Curve For Type Ia Supernova



Method of Distant Measurement

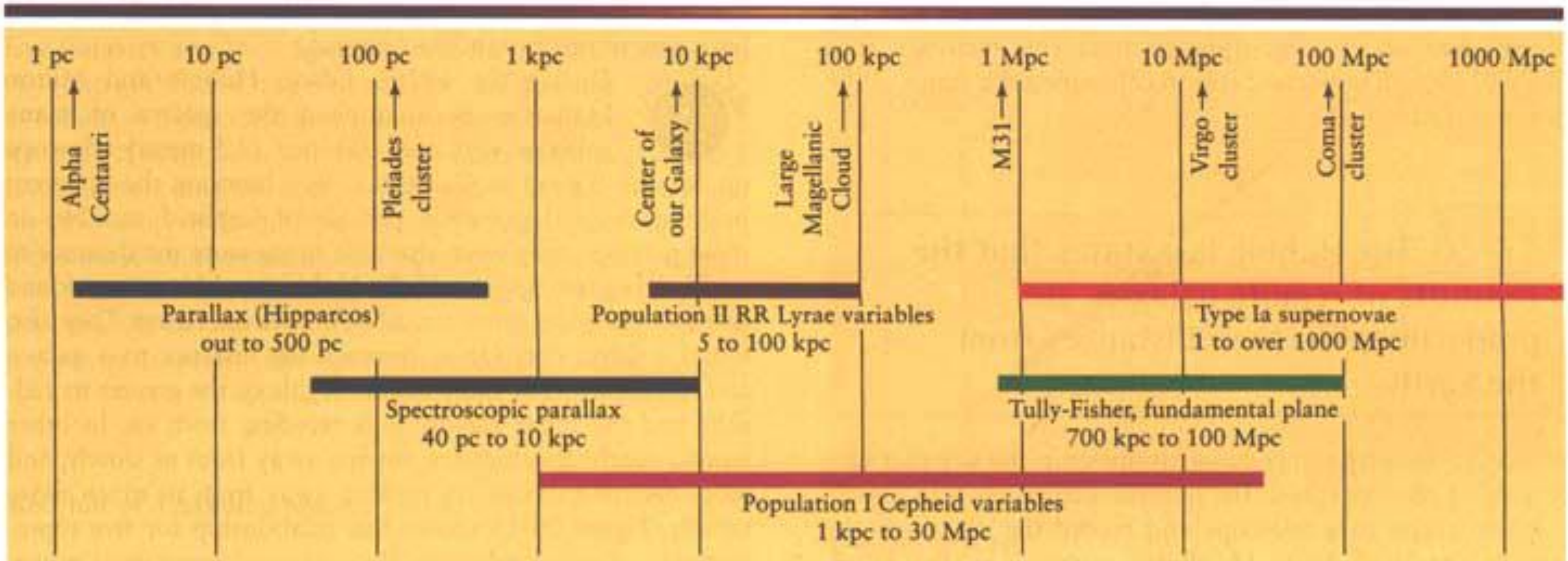
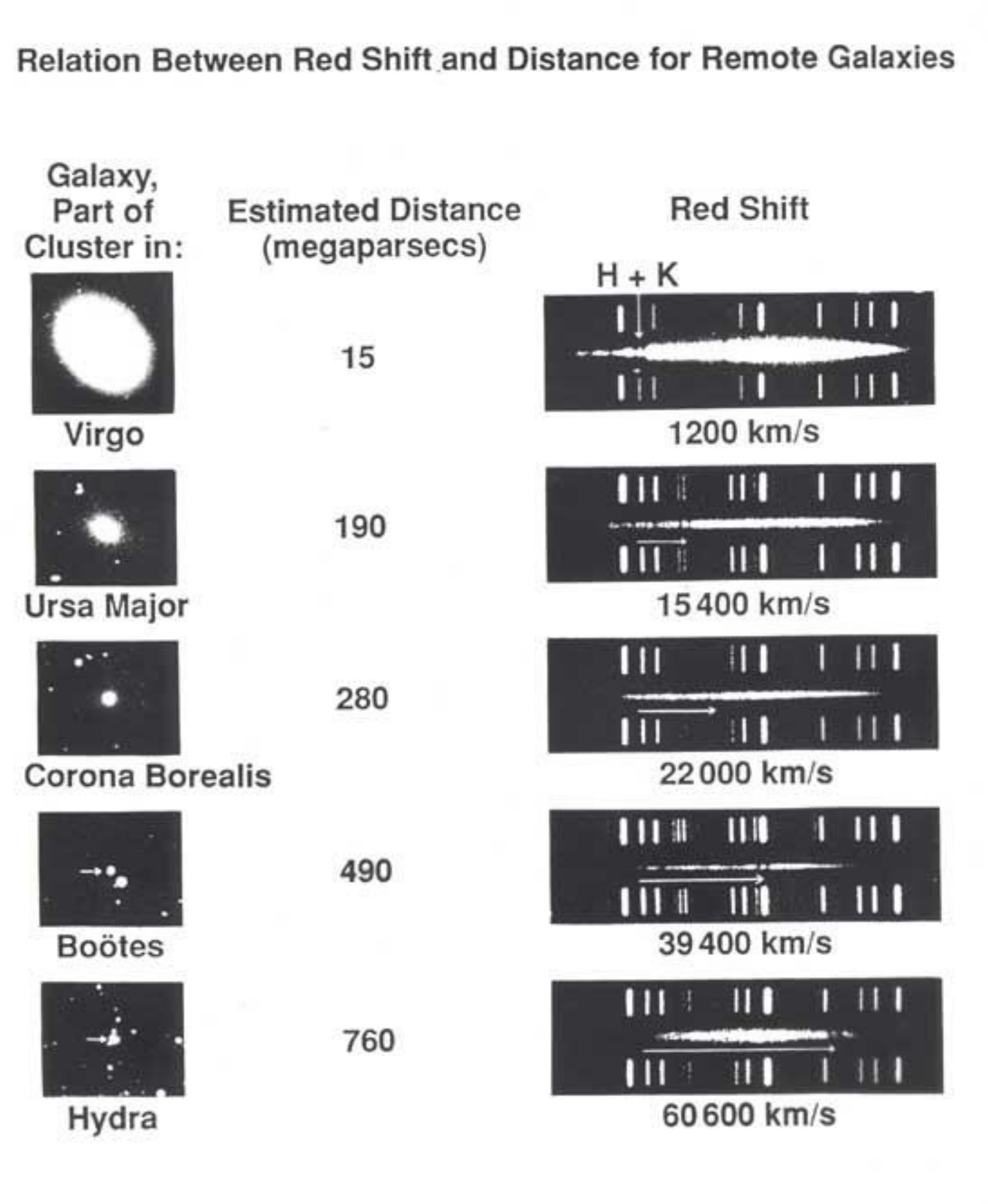


Figure 26-13

The Distance Ladder Astronomers employ a variety of techniques for determining the distances to objects beyond the solar system. Because their ranges of applicability overlap, one technique can be used to calibrate another. The arrows indicate distances to several important objects. Note that each division on the scale indicates a tenfold increase in distance, such as from 1 to 10 Mpc.

$1\ pc = 3.26\ ly = 3.1 \times 10^{16} m$

Hubble Red shift vs Distance



Hubble Diagramin 1929

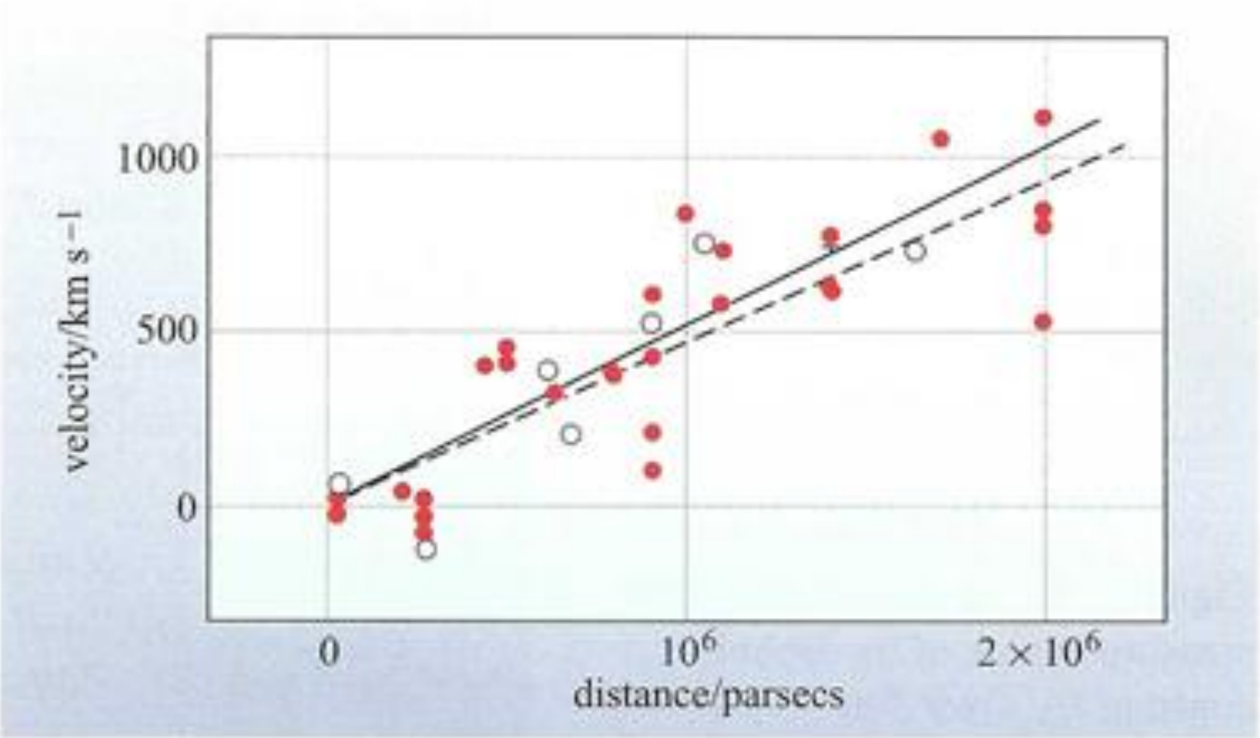


Figure 7.1 The original 'Hubble diagram', based on a figure that appeared in 1929. The 24 galaxies are represented by the red dots; the solid line represents the best straight line through the data. The open circles and the dotted line refer to nine groups of galaxies that Hubble also considered. (Courtesy of the National Academy of Sciences)

Expanding Universe

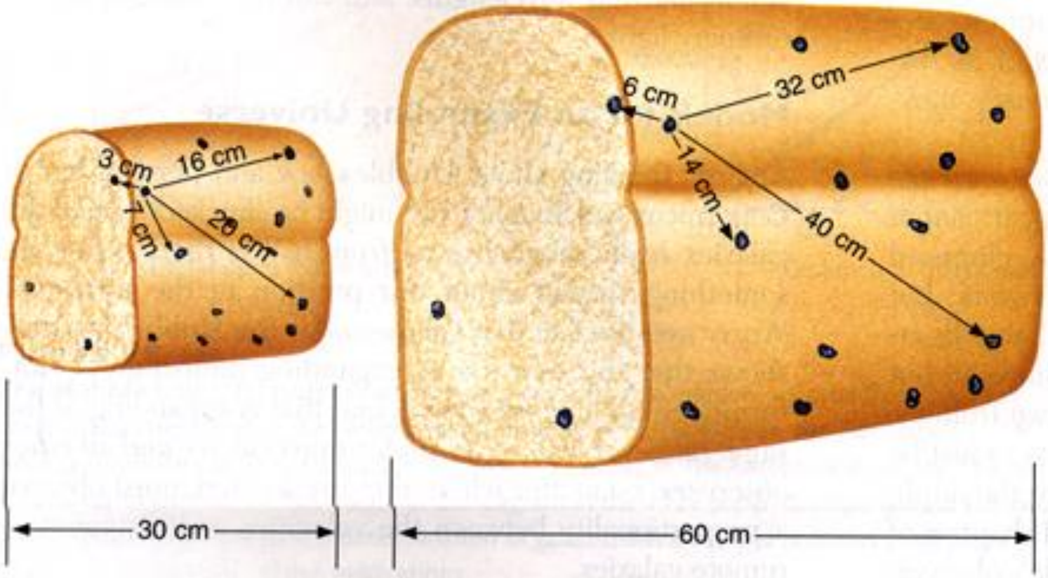


FIGURE 25.20
Expanding Raisin Bread As the raisin bread bakes, the raisins see other raisins moving away. More distant raisins move away faster in a uniformly expanding bread

Historical Values of Hubble Constant

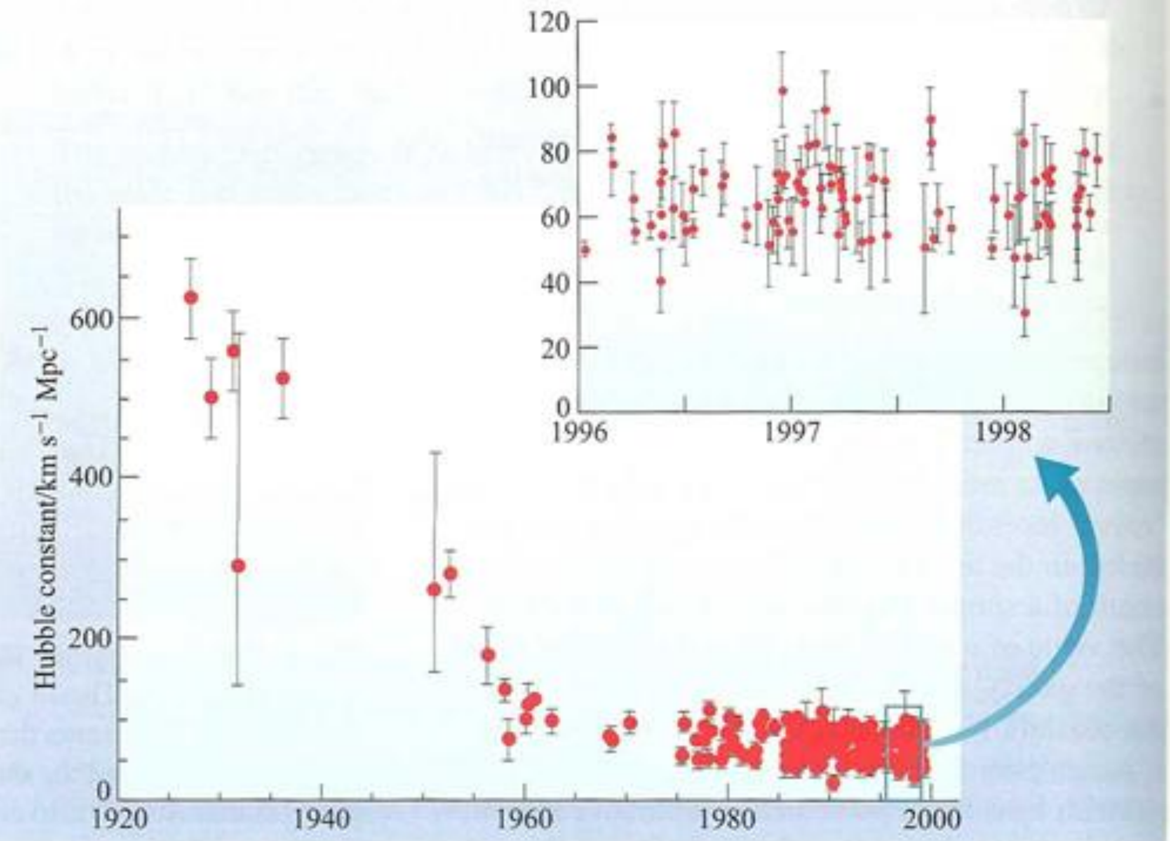
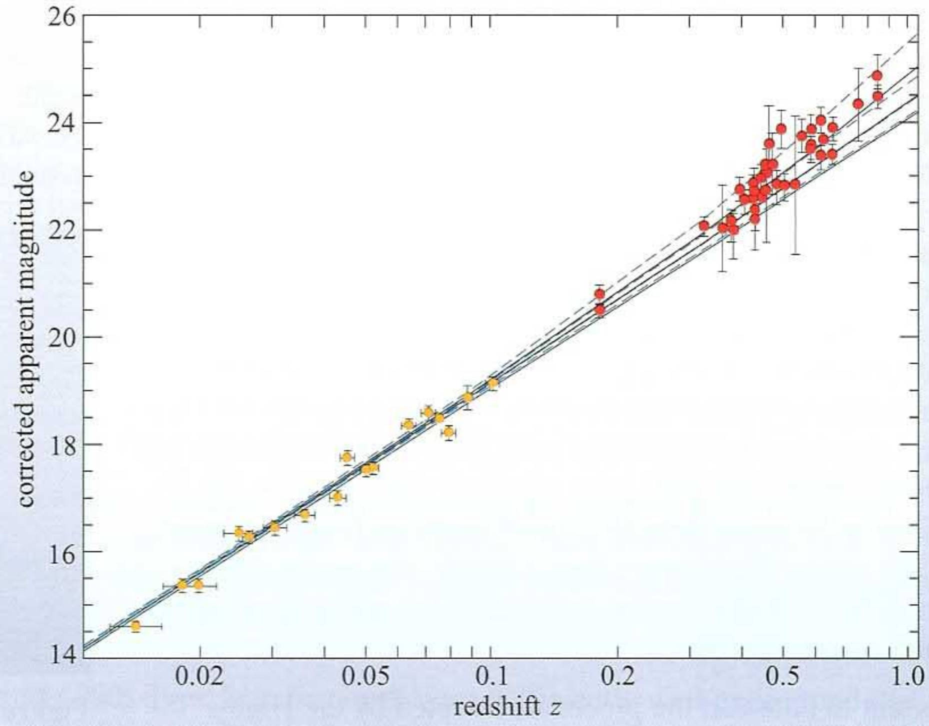


Figure 7.2 The evolution of the measured value of the Hubble constant H_0. Over 300 measurements performed since 1975 have yielded values between 50 and 100 km s^{-1} Mpc^{-1}. (Adapted from *Sky and Telescope*, based on work by J. Huchra and the HST Key Project on the Distance Scale)

Nearby Galaxies from Supernova Ia

Figure 7.10 A plot of apparent magnitude against redshift for Type Ia supernovae that have been 'corrected' for various factors, including the intrinsic differences in brightness indicated by the differing rates of decline of their light curves. The 40 red dots represent observations by the Supernova Cosmology Project. The yellow data points represent the nearer supernovae that were used to calibrate the Type Ia light curve. The various lines shown on the graph correspond to different values of q_0. (Adapted from Schwarzschild, 1998, based on the work of S. Perlmutter *et al.*)



Cosmic Background Radiation – Strongest Evidence of BB

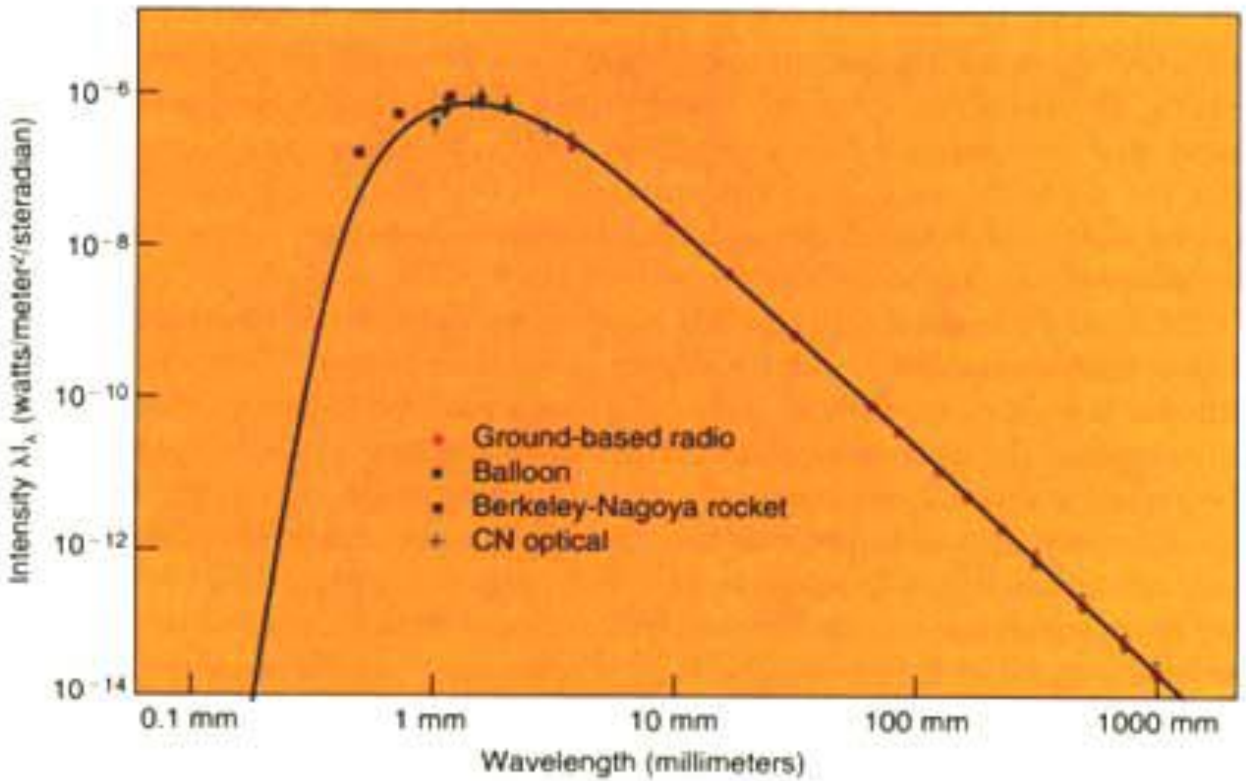


FIGURE 37–16 Observations of the cosmic background radiation as of the time just before the launch of COBE (the Cosmic Background Explorer). The results of a rocket flight that showed an apparent deviation from a black-body curve in the submillimeter region of the spectrum, and thus caused worries that the spectrum was not that of a black body, were not verified by the satellite observations. The results from optical studies of the molecule CN, which can be interpreted to show how radio waves affect the molecules and thus give the strength of the background radiation at those wavelengths, are also shown.

Hubble Constant and Age of Universe

COSMOLOGY

Age of the Universe

	With no cosmological constant	With cosmological constant of 0.7
Ho	Age (Gyr)	Age (Gyr)
55	11.9	17.1
65	10.0	14.5
75	8.7	12.6
85	7.7	11.1

The Relativistic Doppler Shift and Hubble's Law (Motz & Duveen P.610)

$$\nu = \nu_o (1 - v^2/c^2)^{1/2} / (1 \pm v/c)$$

Or

$$\lambda = \lambda_o (1 \pm v/c)/(1 - v^2/c^2)^{1/2}$$

Thus redshfit can be expressed as

$$\Delta\lambda/\lambda = (1 + v/c)/(1 - v^2/c^2)^{1/2} - 1$$

Look back Time

REDSHIT AND LOOKBACK TIME

The relation of redshift and the time that light has taken to travel depends on the curvature of the universe. Here the calculations correspond to the current model: Hubble constant of 75, mass density of 30% and cosmological constant of 70%.

Redshift (z)	Lookback time (billions years)
0	0
0.2	2.46
0.4	4.27
0.6	5.63
0.8	6.67
1.0	7.49
1.5	8.89
2.0	9.80
2.5	10.33
3.0	10.73
4.0	11.25
5.0	11.57
6.0	11.77
Infinity	12.57

Redshift z	Size of Universe Compared to Now	Length of Time Ago	Time After Big Bang
0	1	Today	13.7 billion years
0.1	0.91	1.3 billion years	12.4 billion years
0.5	0.67	5.0 billion years	8.7 billion years
1.0	0.50	7.7 billion years	5.9 billion years
2.0	0.33	10.3 billion years	3.4 billion years
3.0	0.25	11.5 billion years	2.2 billion years
5.0	0.17	12.5 billion years	1.2 billion years
7.0	0.13	12.9 billion years	800 million years
10	0.09	13.2 billion years	500 million years
1000	0.001	13.7 billion years	400,000 years

effects give an answer that is very close to the age we have calculated: 13.7 billion years. Table 1 shows how much the universe has expanded for different values of the redshift according to the best current model.

Inflational Universe

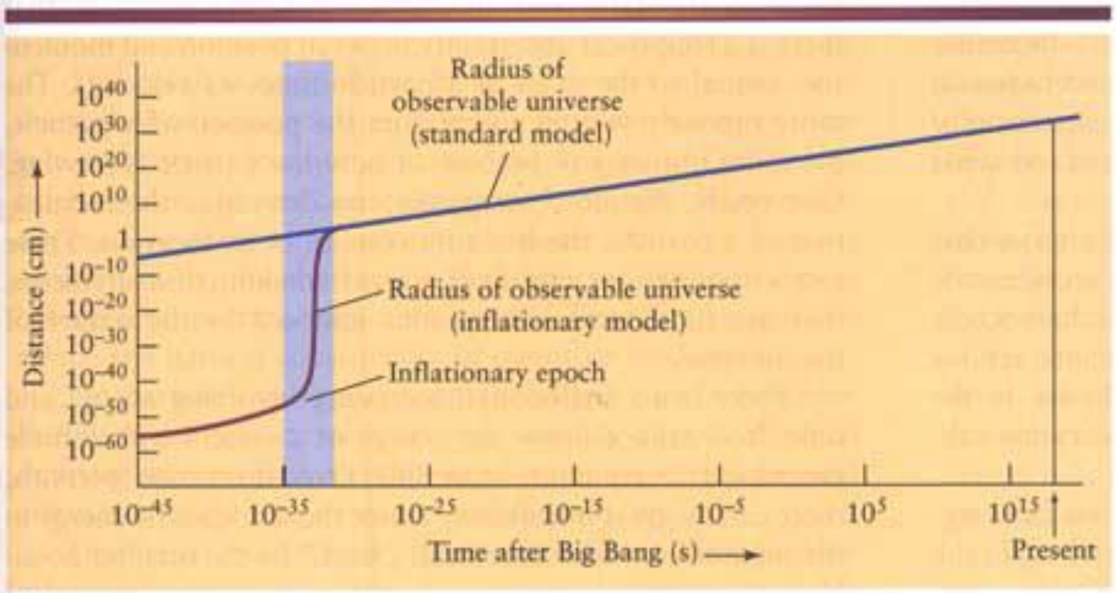
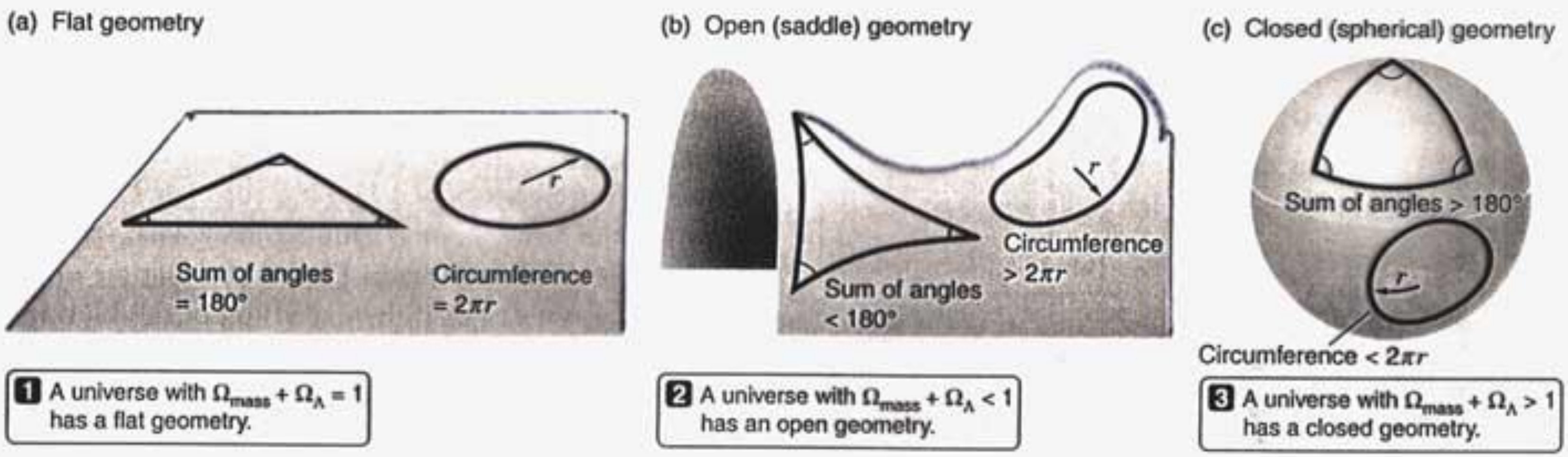


Figure 29-2

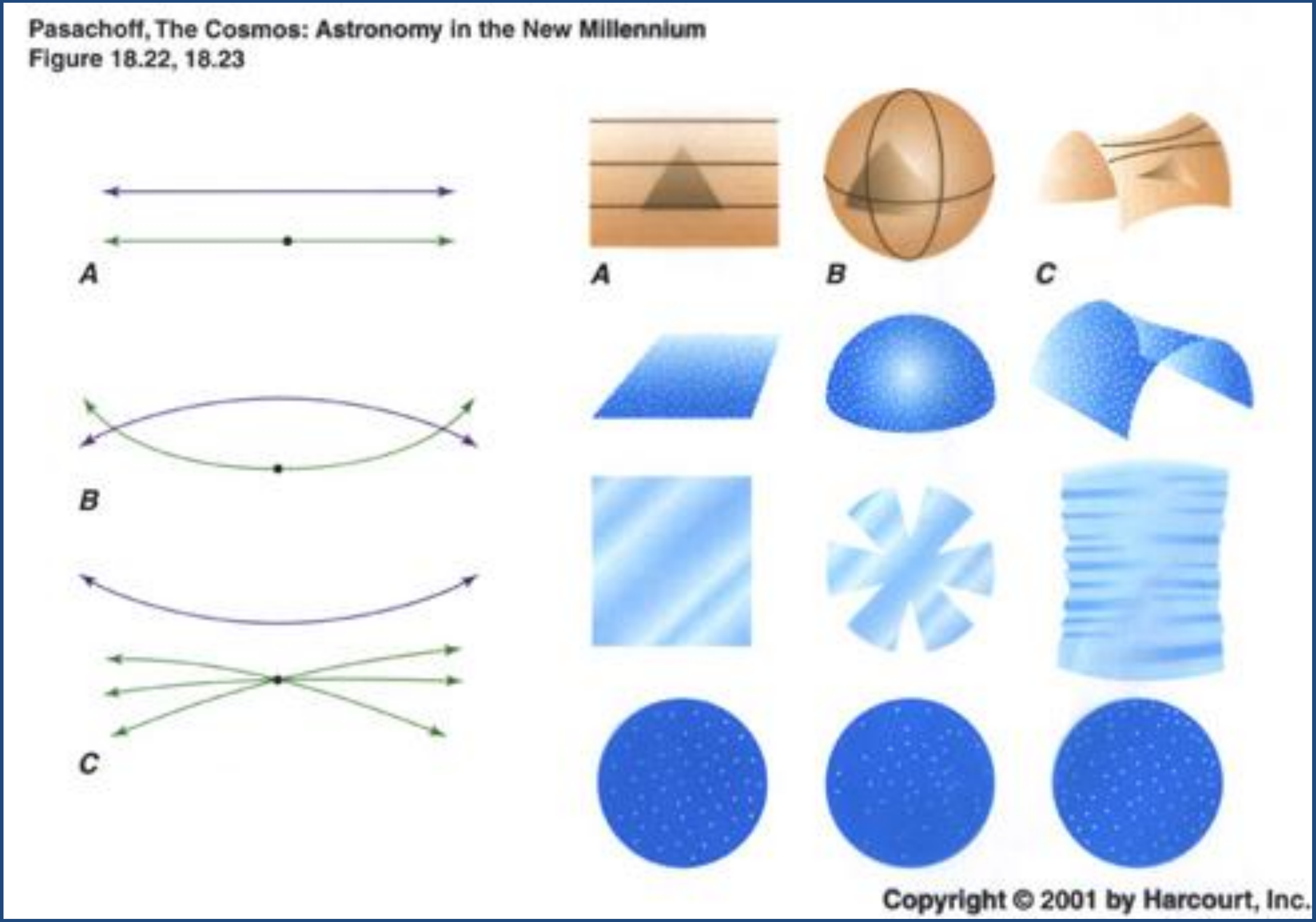
The Observable Universe With and Without Inflation According to the inflationary model (shown in red), the universe expanded by a factor of about 10^{50} shortly after the Big Bang. This growth in the size of the observable universe probably occurred during a very brief interval, as indicated by the vertical shaded area on the graph. For comparison, the projected size of the universe without inflation is shown in blue. (Adapted from A. Guth)

Geometries of Universe

Figure 19.24 *Two-dimensional representations of the possible geometries that space can have in a Universe.* (a) *In a flat universe, Euclidean geometry holds. Triangles have angles that sum to 180°, and the circumference of a circle equals 2π times the radius. In* (b), *an open universe, or* (c), *a closed universe, these relationships are no longer correct over very large distances.*



Geometry of Distribution



All-Sky CMB Anisotropy Map

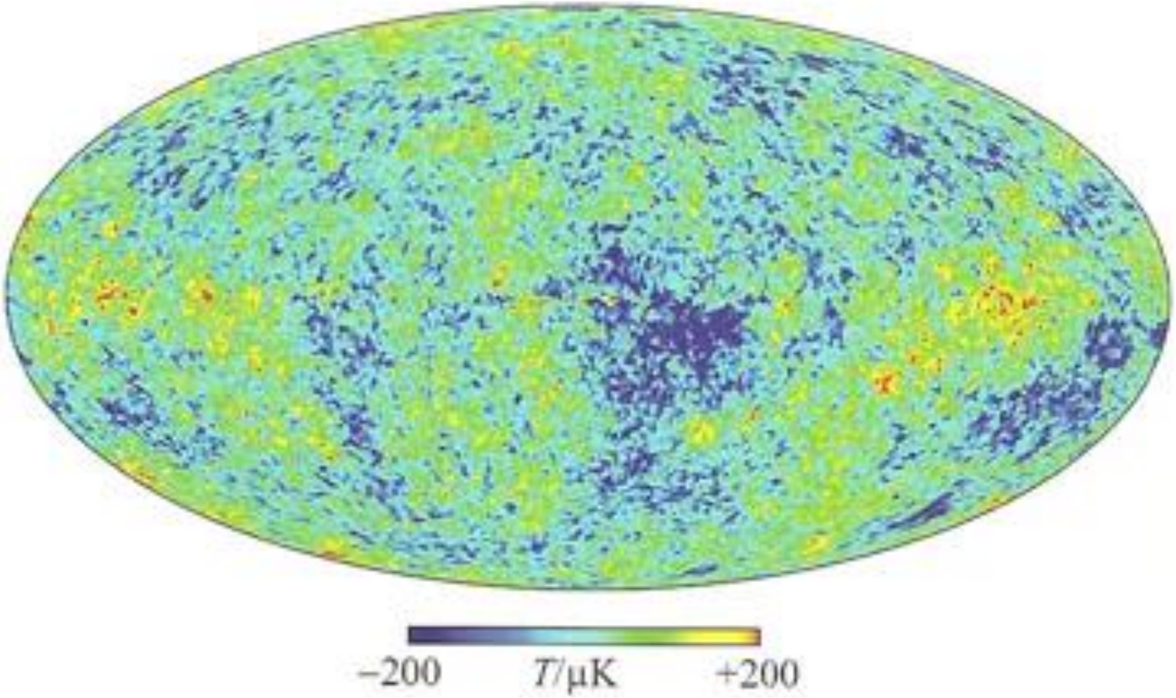
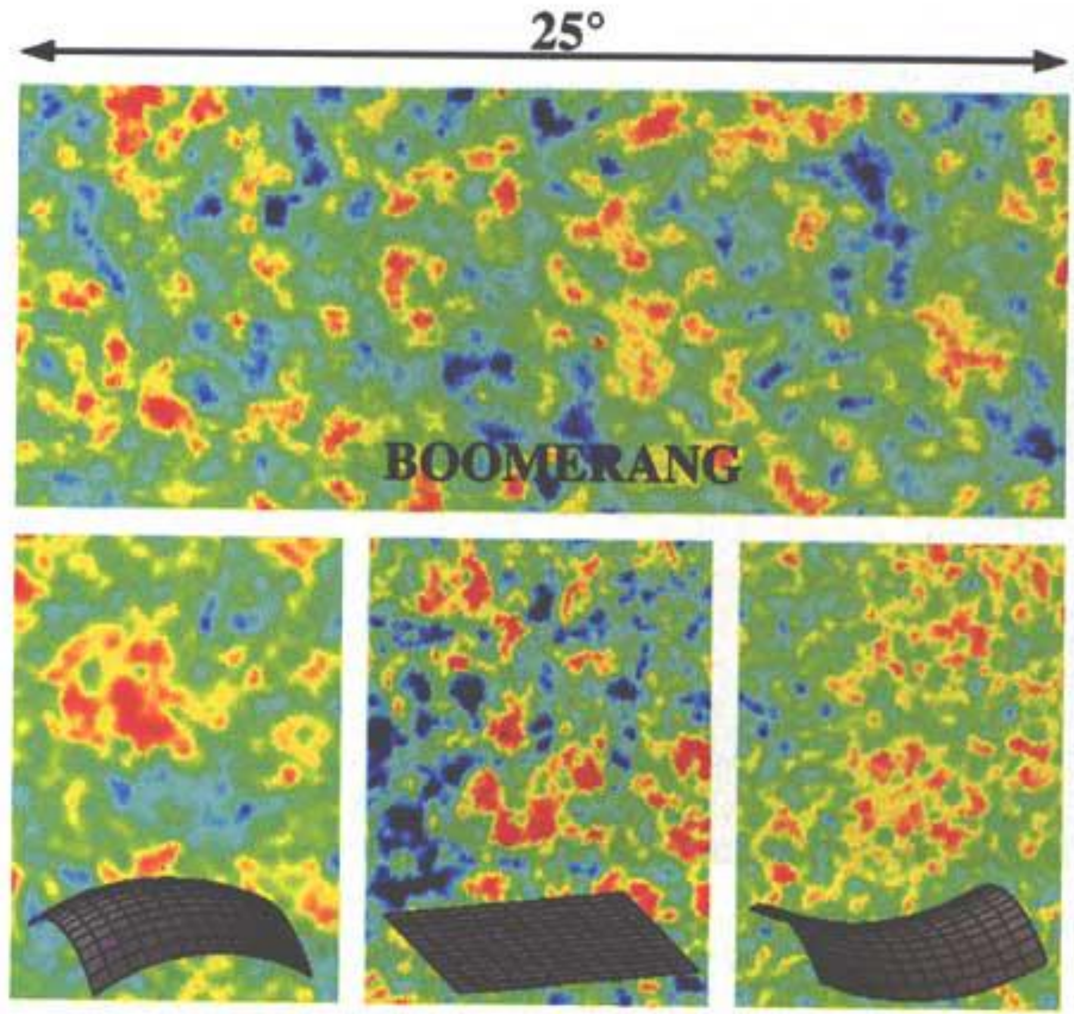


Figure 7.21 An all-sky CMB anisotropy map, based on data obtained by the WMAP space probe. The angular resolution of this map is about 0.1°. Compare this map with the lower resolution COBE data shown in Figure 7.15.
(Bennett *et al*., 2003)

Flat Universe

FIGURE 37-25 The results on the size of fluctuations show that the universe is flat, neither open nor closed. The observations (*top*) agree much better with the calculated model for flat (*bottom middle*) than those for curved universes (*bottom left and bottom right*).



Angular Size Fluctuation Confirms Flat Universe

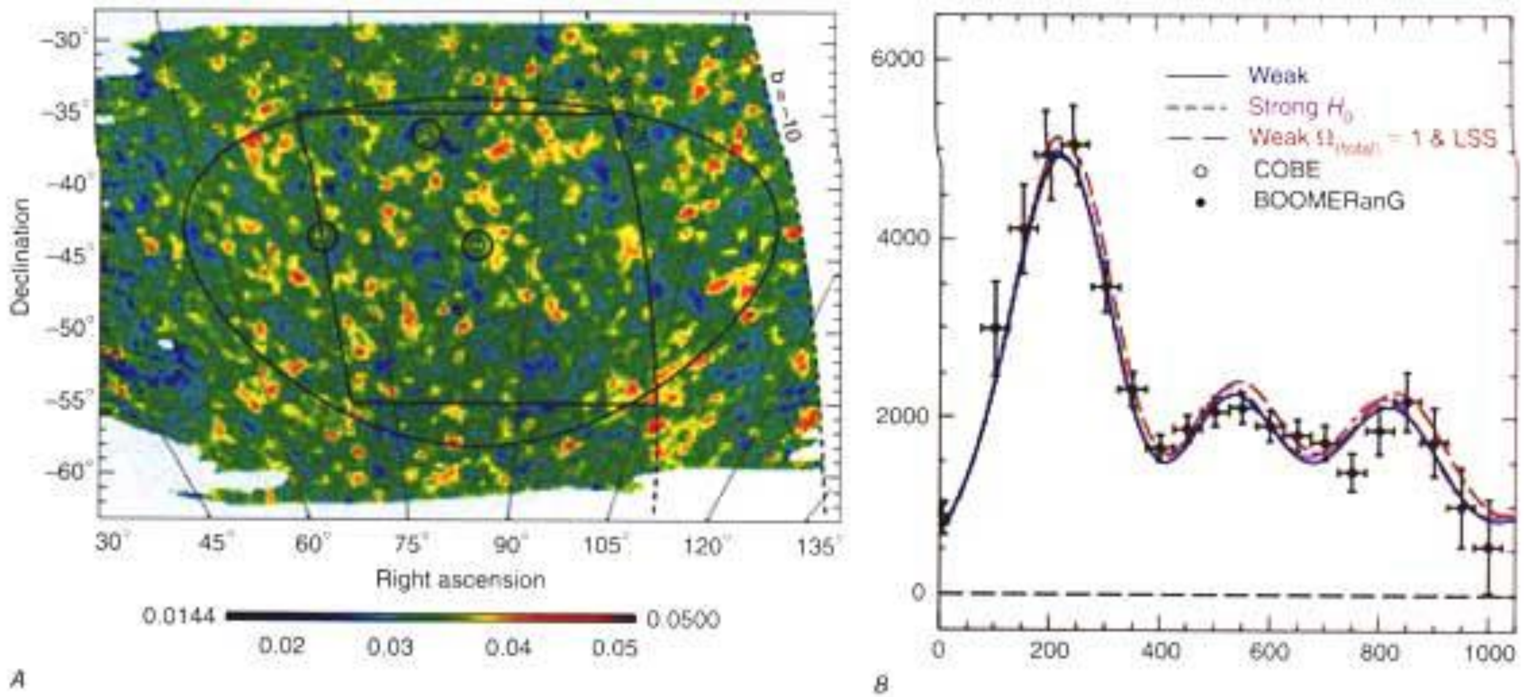


FIGURE 38–28 (*A*) The BOOMERanG data released in 2001, an intensity map covering a larger region (the ellipse) than that used for the 2000 data reduction (the parallelogram). The reduction of the larger region showed three peaks in the fluctuations, as shown in Figure 37–28(*A*), indicating that the universe is flat and allowing the percentage of baryons in the universe to be calculated. Some point sources, quasars, that were omitted from the data reduction are circled. (*B*) The reduction of the data from the larger region showed three peaks in the graph of the sizes of the fluctuations versus their relative numbers (compare with Figures 37–26 and 37–28. The size and position of the peaks in the graph indicate that the universe is flat and allows the percentage of baryons in the universe to be calculated. (Do not confuse such diagrams of fluctuation peaks with Planck curves.) DMR was a COBE instrument and B98 refers to the 1998 BOOMERanG flight. LSS stands for "large scale structure."

Einstein's Cosmological Constant

Cosmology

General Relativity
Homogeneous and Isotropic Cosmology (Rowan-Robinson), p 232
How can we make models for the large-scale structure of the universe within the framework of general relativity? Shortly after introducing his general theory, Einstein made the daring speculation that on the large scale the structure of the universe is *homogenous*, that is, every region is the same as every other region, and *isotropic*, that is, the universe looks the same in every direction. This is called the cosmological principle. It is almost the strongest assumption that can be made about the simplicity of the universe. Model of based on the cosmological principle have proved to be surprisingly successful in describing the large-scale structure of the universe.

We can now outline how the properties of homogeneous and isotropic cosmological models are derived in general relativity (but without going into mathematical details). It can be shown tha the metric for homogeneous and isotropic models of the universe takes the form

$$ds^2 = dt^2 - [R^2(t)/C^2]\, d\sigma^2 \qquad (5.4)$$

where R(t) is a function of time, called the *scale factor* (see below) and $d\sigma^2$ is the metric for a three dimensional space with constant curvature.

The way in which the scale-factor R varies with time has to be determined by substituting the metric (5.4) into the field equations. For a homogeneous gas of density $\rho(t)$ and pressure p(t), two equations results:

$$\ddot{R} = - 4\pi G (\rho + 3p/c) R/3 + \Lambda R/3 \qquad (5.7)$$

$$\dot{R}^2 = 8\pi G\rho R^2/3 - kc^2 + \Lambda R^2/3 \qquad (5.8)$$

Here G is the usual gravitational constant, but is a new constant, the *cosmological constants*, which appears in the most general form of the general theory of relativity. Einstein regretted introducing the term, and most relativists of earlier days preferred, Λ = 0. The constant can be positive of negative value. The most recent research tends to suggest that = 0.7. This suggests that the mass contribution is 0.3 the universe is accelerating and flat!

Supernova Ia result of Recent Development on Cosmology

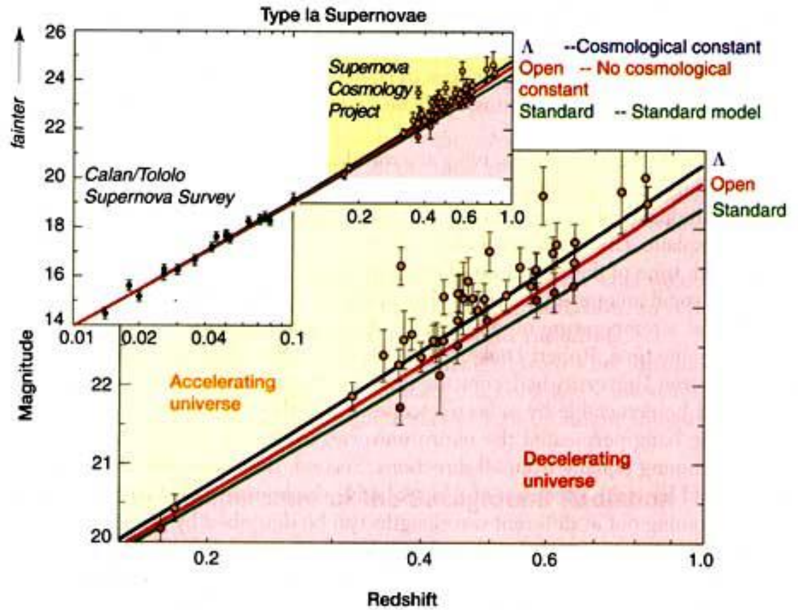


FIGURE 37–12 This observational Hubble diagram is the result of observations of many distant Type Ia supernovae (the kind that come from incinerated white dwarfs in binary systems), as observed with the Supernova Cosmology Project. The lower-redshift part of the diagram is from a ground-based survey. The Supernova Cosmology Project's part of the upper-left diagram, for $z = 0.2$ to 1.0, is magnified in the lower right part of the diagram. Magnitude, shown on the y-axis, measures distance, since galaxies that are farther away are fainter. By convention, this diagram is plotted with magnitude (distance) on the y-axis and redshift on the x-axis, unlike our earlier Hubble diagrams, which had the axes interchanged. In principle, we can determine the future of the universe from the slight deviations of the measured curves from the straight-line Hubble law, especially at high redshift. On the curve for the "Standard" model, the universe is positively curved and is closed. It is finite, and would eventually begin to contract. For the curve for the "Open" model, the universe would be open, is infinite, and will expand forever. The surprising result of recent years is that the observations show that the distant supernovae are, in the range shown, somewhat fainter than expected (and thus higher on the graph). The best fit to the observations thus indicates that the expansion of the universe is accelerating, not decelerating after all. The observations are fit best in models with a cosmological constant Λ of 70%, that is, $\Lambda = 0.7$.

On the graph, the "lambda" curve corresponds to the currently best accepted model: lambda of 0.7 and mass contribution of 0.3; the "open" curve has lambda of 0 (that is, no contribution from a cosmological constant) and mass contribution of 0.3; and the "standard" curve has lambda at 0 and mass contribution of 1, that is, mass density at the critical density.

Impact of Type Ia On Modern Cosmology

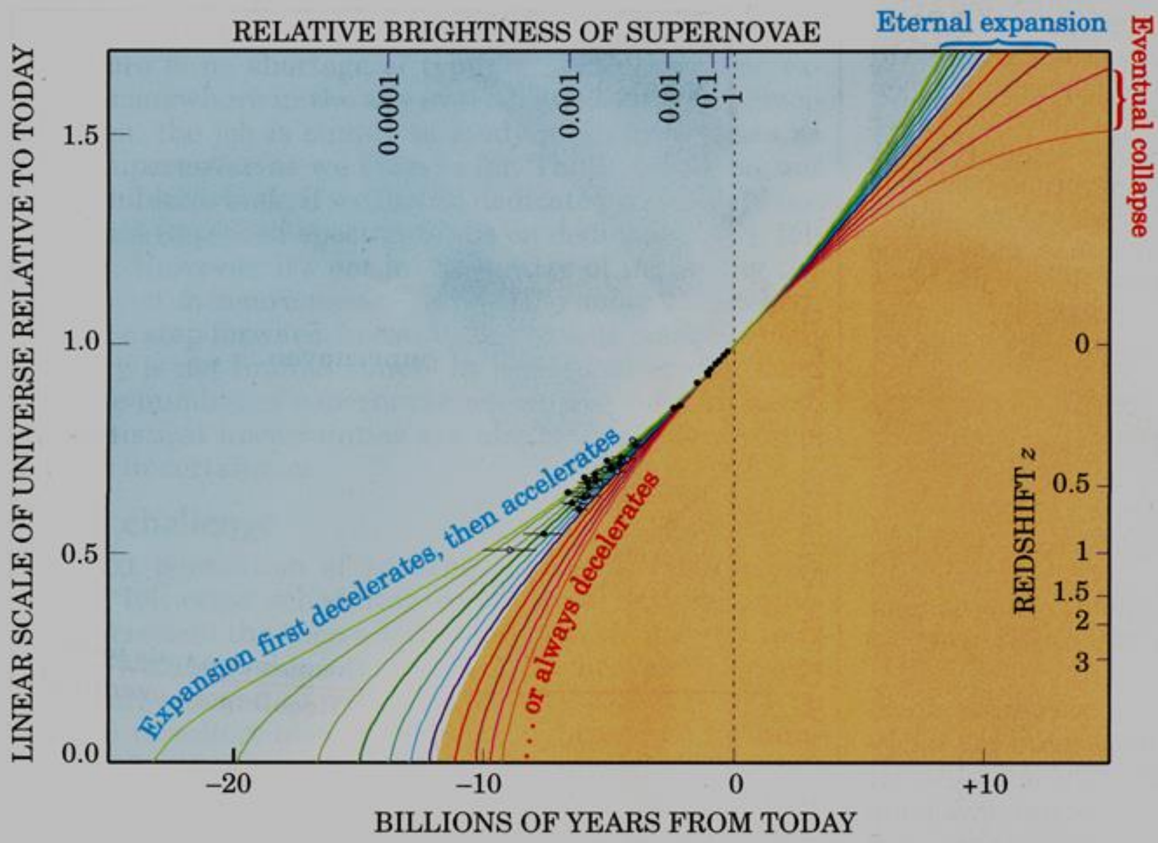


Figure 4. The history of cosmic expansion, as measured by the high-redshift supernovae (the black data points), assuming flat cosmic geometry. The scale factor R of the universe is taken to be 1 at present, so it equals $1/(1 + z)$. The curves in the blue shaded region represent cosmological models in which the accelerating effect of vacuum energy eventually overcomes the decelerating effect of the mass density. These curves assume vacuum energy densities ranging from 0.95 ρ_c (top curve) down to 0.4 ρ_c. In the yellow shaded region, the curves represent models in which the cosmic expansion is always decelerating due to high mass density. They assume mass densities ranging (left to right) from 0.8 ρ_c up to 1.4 ρ_c. In fact, for the last two curves, the expansion eventually halts and reverses into a cosmic collapse.

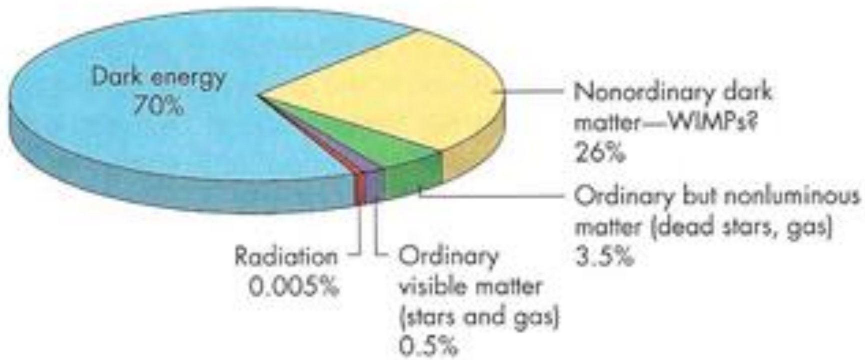


FIGURE 82.5
The makeup of the universe as deduced from observations of the brightness variations in the cosmic microwave background and other data. The percentages have been rounded off, so they do not add up to exactly 100%.

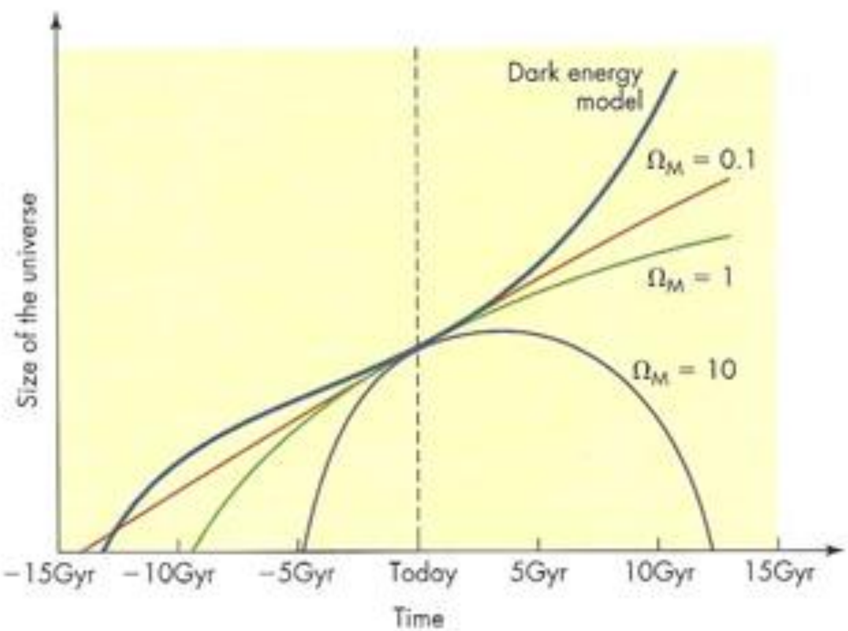


FIGURE 82.6
A universe with dark energy will accelerate more rapidly in the future.

END

- THE END

Common Envelope Evolution

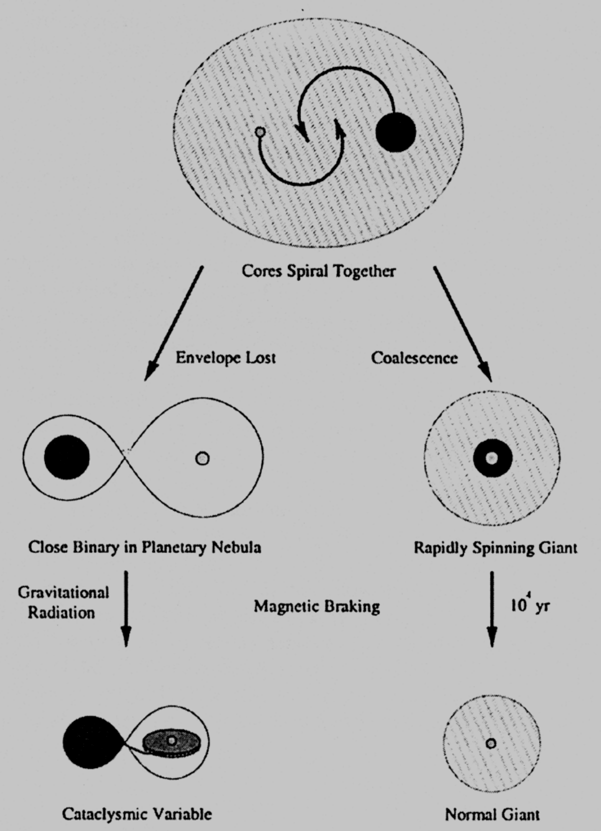


Figure 2. Common-envelope evolution. After dynamical mass transfer from a giant, a common envelope enshrouds the relatively dense companion and the core of the original giant. These two spiral together as their orbital energy is transferred to the envelope until either the entire envelope is lost or they coalesce. In the former case a close white-dwarf and main-sequence binary is left, initially as the core of a planetary nebula. Magnetic braking or gravitational radiation may shrink the orbit and create a cataclysmic variable. Coalescence results in a rapidly rotating giant which will very quickly spin down by magnetic braking.