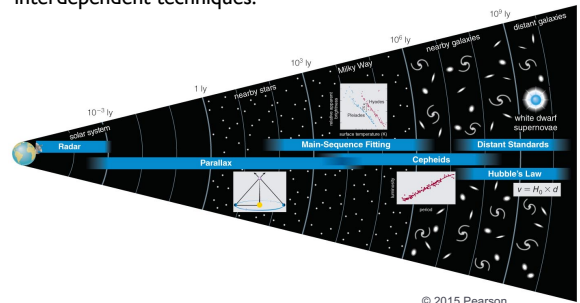


26.4 THE EXTRAGALACTIC DISTANCE SCALE

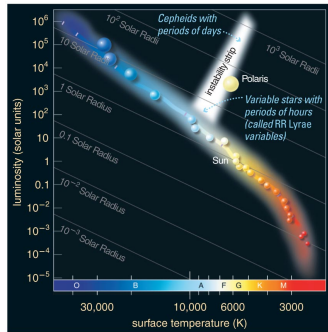


► **M101, the Pinwheel Galaxy.** This galaxy is a face-on spiral at a distance of 21 million light-years. M101 is almost twice the diameter of the Milky Way, and it contains at least 1 trillion stars. (credit: NASA, ESA, K. Kuntz (Johns Hopkins University), F. Bresolin (University of Hawaii), J. Trauger (Jet Propulsion Lab), J. Mould (NOAO), Y.-H. Chu (University of Illinois, Urbana), and STScI)

We measure galaxy distances using a chain of interdependent techniques.



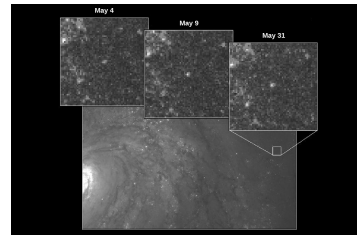
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Cepheid variable star tells us its luminosity, we can use these stars as standard candles

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Figure 26.11



► **Cepheid Variable Star.** In 1994, using the Hubble Space Telescope, astronomers were able to make out an individual cepheid variable star in the galaxy M100 and measure its distance to be 56 million light-years. The insets show the star on three different nights; you can see that its brightness is indeed variable. (credit: modification of work by Wendy L. Freedman, Observatories of the Carnegie Institution of Washington, and NASA/ESA)



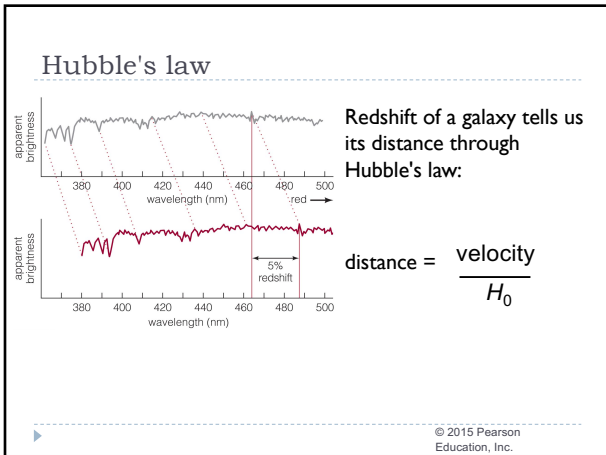
White dwarf supernovae can also be used as standard candles.

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Figure 26.12



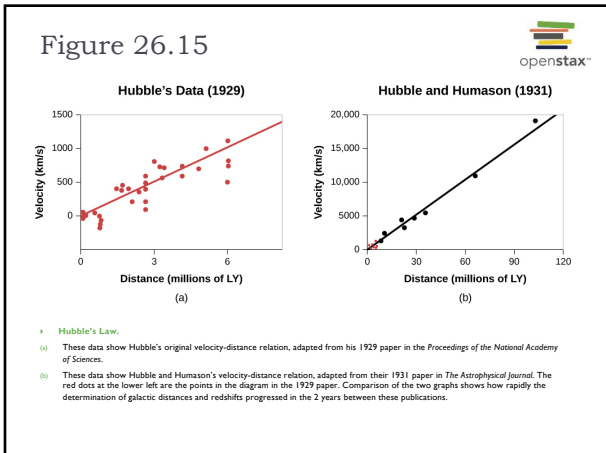
► **Type Ia Supernova.** The bright object at the bottom left of center is a type Ia supernova near its peak intensity. The supernova easily outshines its host galaxy. This extreme increase and luminosity help astronomers use the supernova as standard bulbs. (credit: NASA, ESA, A. Riess (STScI))



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Figure 26.13

- ▶ **Vesto M. Slipher (1875–1969).** Slipher spent his entire career at the Lowell Observatory, where he discovered the large radial velocities of galaxies. (credit: Lowell Observatory)
- ▶ **Milton Humason (1891–1972).** Humason was Hubble's collaborator on the great task of observing, measuring, and classifying the characteristics of many galaxies. (credit: Caltech Archives)



26.5 THE EXPANDING UNIVERSE

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▶ **Stretching a Ruler:** Ants on a stretching ruler see other ants move away from them. The speed with which another ant moves away is proportional to its distance.

Figure 26.17

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▶ **Expanding Raisin Bread.** As the raisin bread rises, the raisins "see" other raisins moving away. More distant raisins move away faster in a uniformly expanding bread.

Dots move apart as the balloon expands, like galaxies in the expanding universe.

Another example of something that expands but has no center or edge is the surface of a balloon.

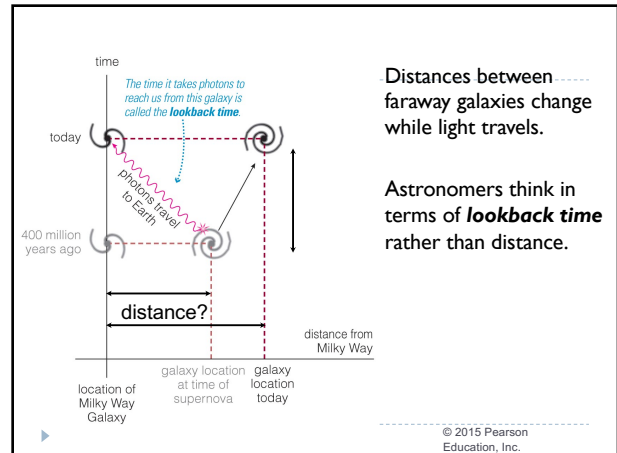
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Cosmological Principle

The universe looks about the same no matter where you are within it.

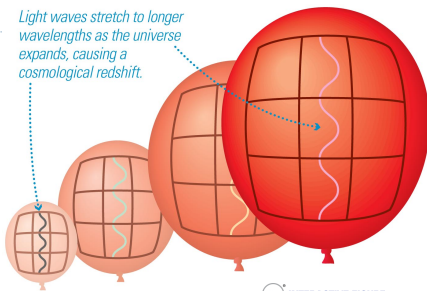
- ▶ Matter is evenly distributed on very large scales in the universe.
- ▶ No center and no edges
- ▶ Not proved but consistent with all observations to date

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Light waves stretch to longer wavelengths as the universe expands, causing a cosmological redshift.



INTERACTIVE FIGURE

Expansion stretches photon wavelengths, causing a **cosmological redshift** directly related to lookback time.

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Links

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- ▶ [black hole ch25 4 min](#)
- ▶ [worm hole ch 25 2 min](#)
- ▶ [gravitational waves ch24 3 min](#)
- ▶ [gray way brian greene](#)
- ▶ [brian greene time 10 min cut7](#)

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