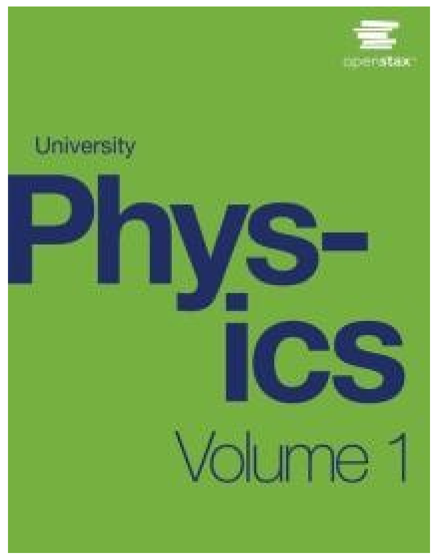
UNIVERSITY PHYSICS

Chapter 13 GRAVITATION

PowerPoint Image Slideshow



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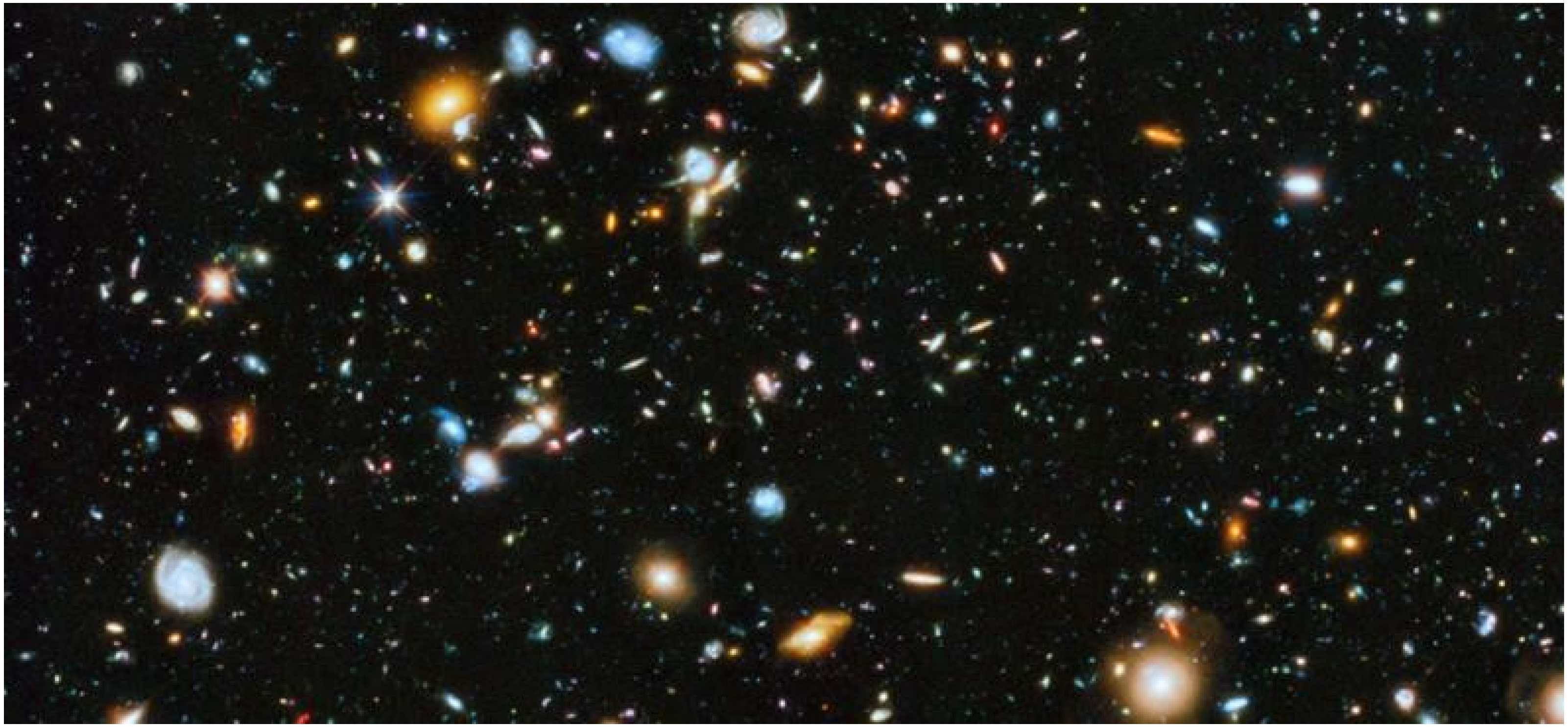
Gravity

$$F_{12}=\frac{G\,m_1\,m_2}{r_{12}^2}$$

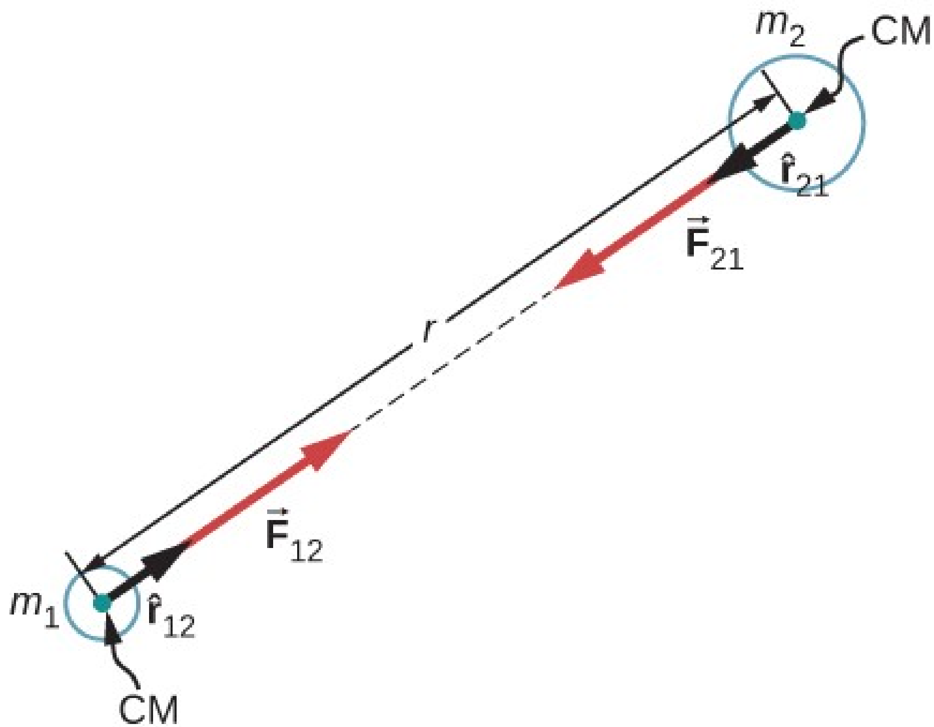
$$G=6.6743\times10^{-11}\frac{m^3}{kg^1\,s^2}$$

FIGURE 13.1



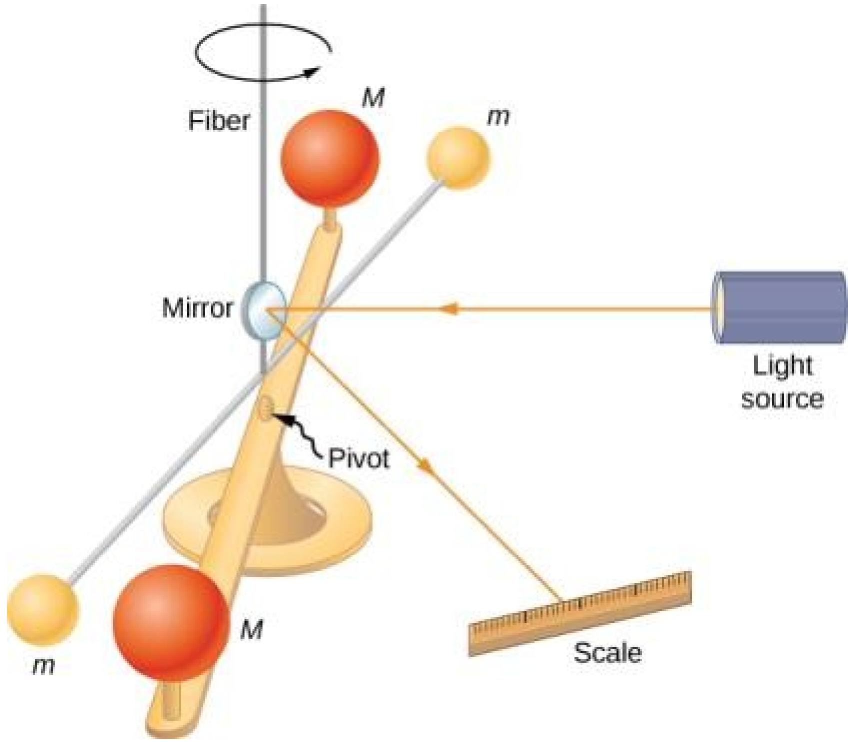
Our visible Universe contains billions of galaxies, whose very existence is due to the force of gravity. Gravity is ultimately responsible for the energy output of all stars—initiating thermonuclear reactions in stars, allowing the Sun to heat Earth, and making galaxies visible from unfathomable distances. Most of the dots you see in this image are not stars, but galaxies. (credit: modification of work by NASA)

FIGURE 13.2



Gravitational force acts along a line joining the centers of mass of two objects.

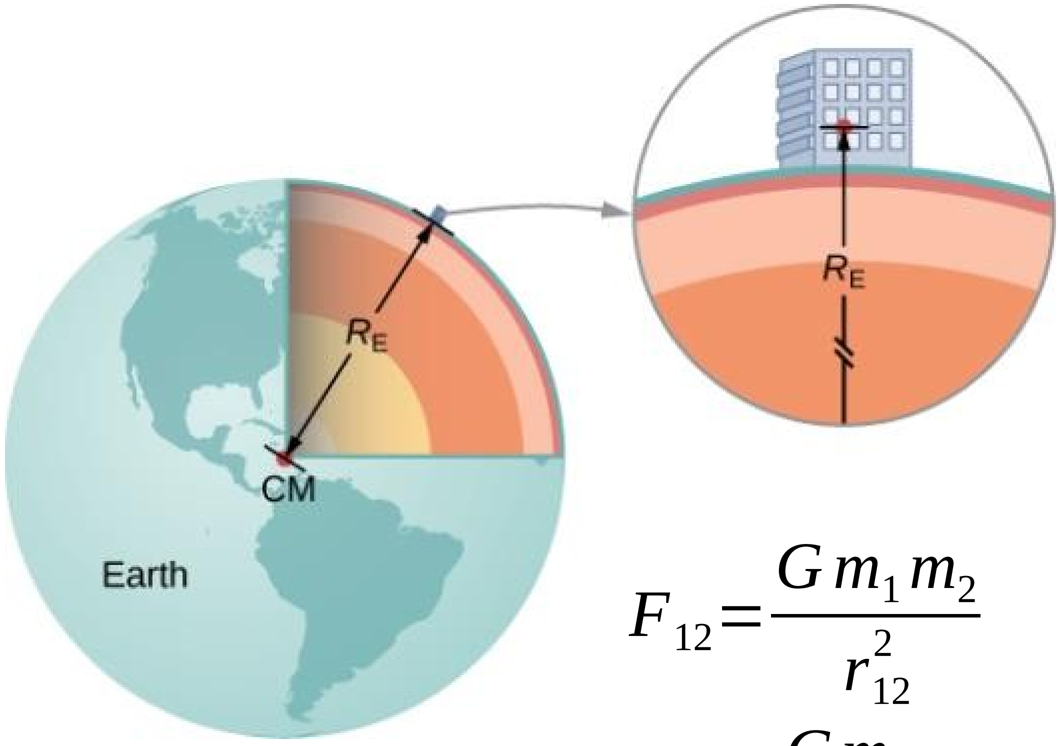
FIGURE 13.3



Cavendish used an apparatus similar to this to measure the gravitational attraction between two spheres (*m*) suspended from a wire and two stationary spheres (*M*). This is a common experiment performed in undergraduate laboratories, but it is quite challenging. Passing trucks outside the laboratory can create vibrations that overwhelm the gravitational forces.

Gravitational constant & field

FIGURE 13.7



$$F_{12} = \frac{G m_1 m_2}{r_{12}^2}$$

$$g = \frac{G m_E}{r_E^2}$$

We can take the distance between the centers of mass of Earth and an object on its surface to be the radius of Earth, provided that its size is much less than the radius of Earth.

FIGURE 13.10

For $r < R_E$, the value of g for the case of constant density is the straight green line. The blue line from the PREM (Preliminary Reference Earth Model) is probably closer to the actual profile for g.

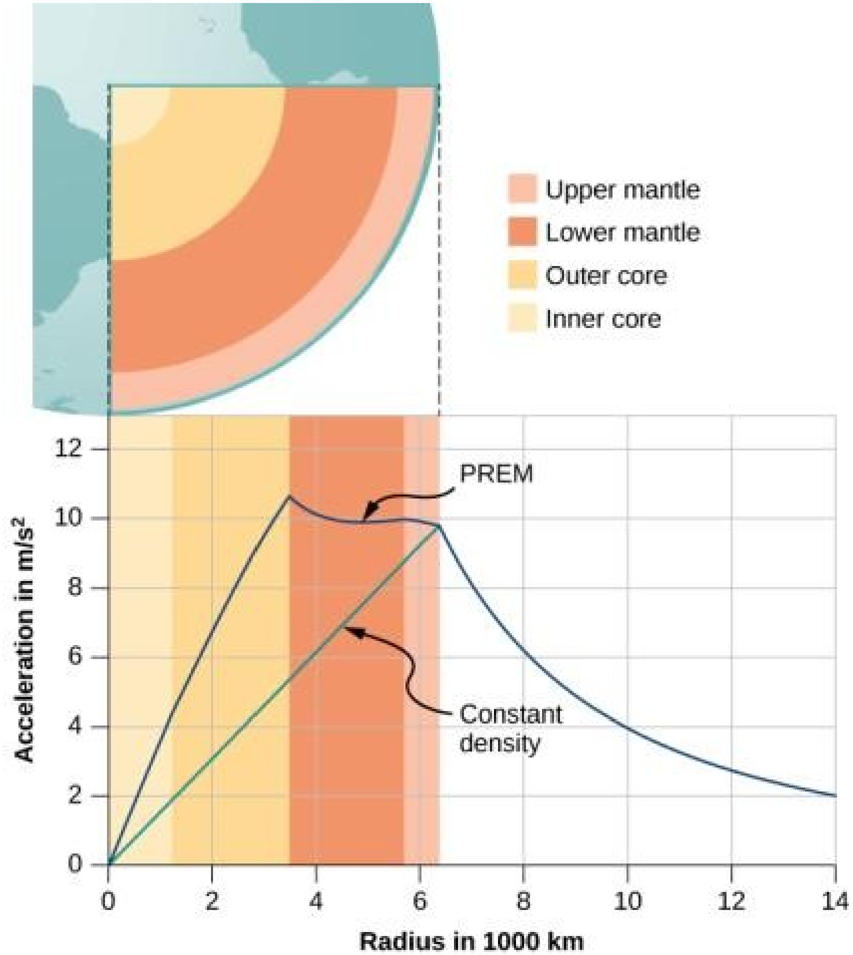
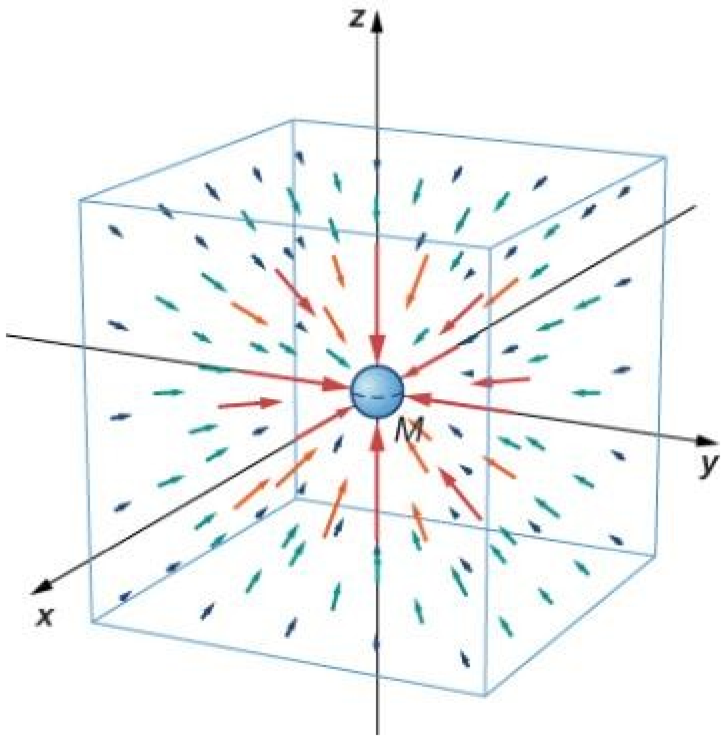
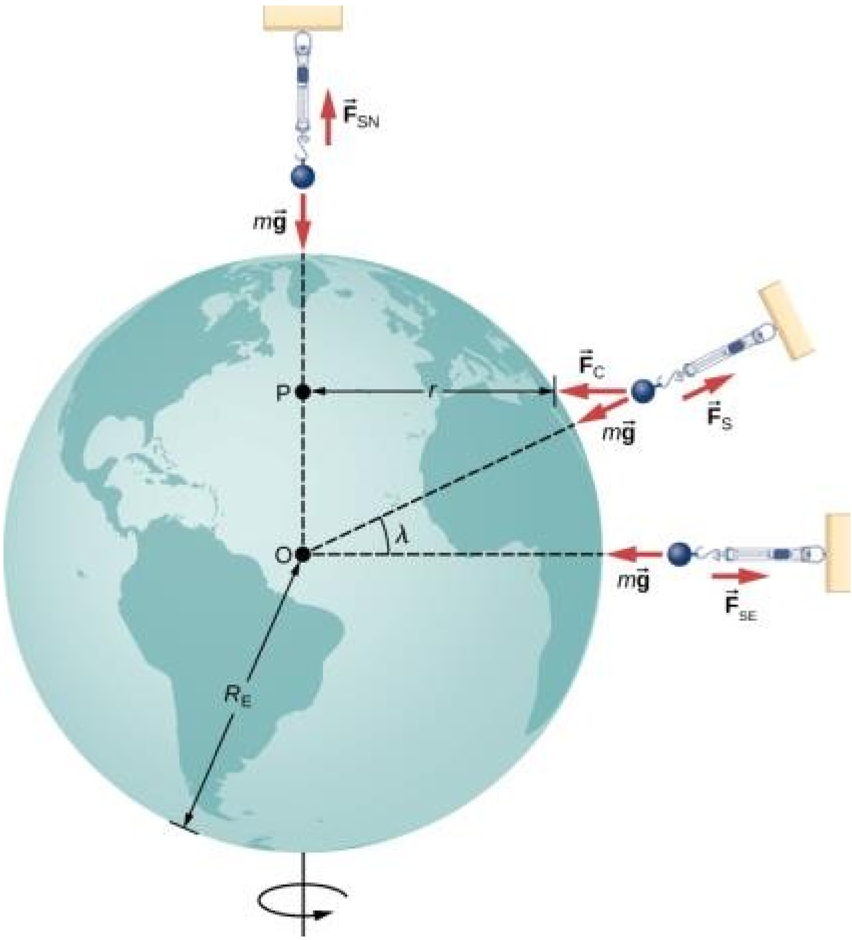


FIGURE 13.8



A three-dimensional representation of the gravitational field created by mass *M*. Note that the lines are uniformly distributed in all directions. (The box has been added only to aid in visualization.)

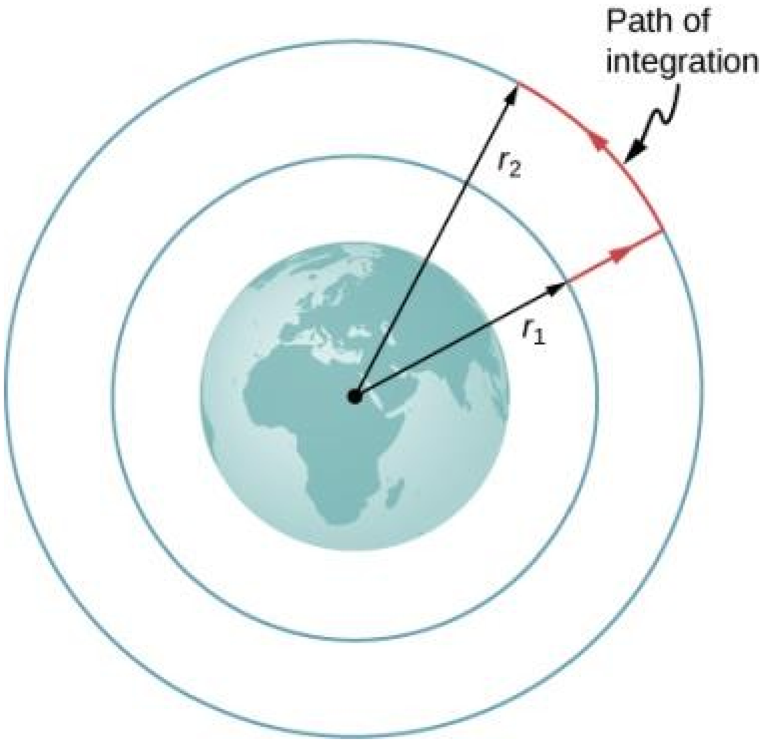
FIGURE 13.9



For a person standing at the equator, the centripetal acceleration (a_c) is in the same direction as the force of gravity. At latitude λ, the angle the between a_c and the force of gravity is λ and the magnitude of a_c decreases with $\cos\lambda$.

Work

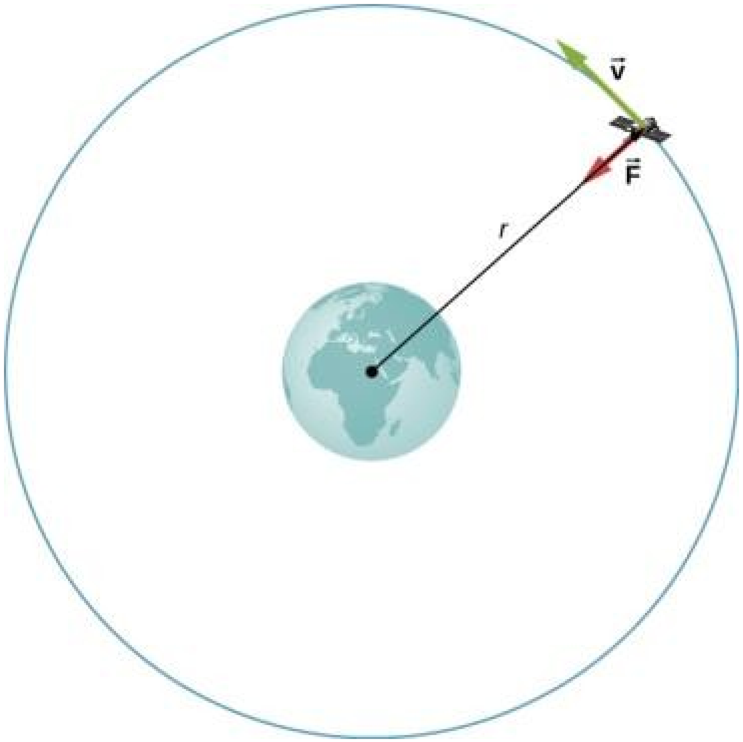
FIGURE 13.11



The work integral, which determines the change in potential energy, can be evaluated along the path shown in red.

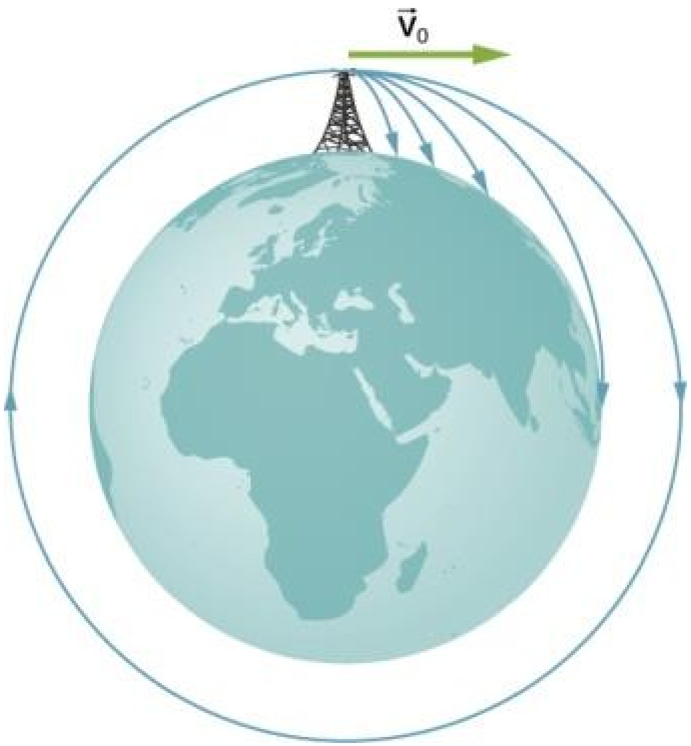
Orbits

FIGURE 13.12



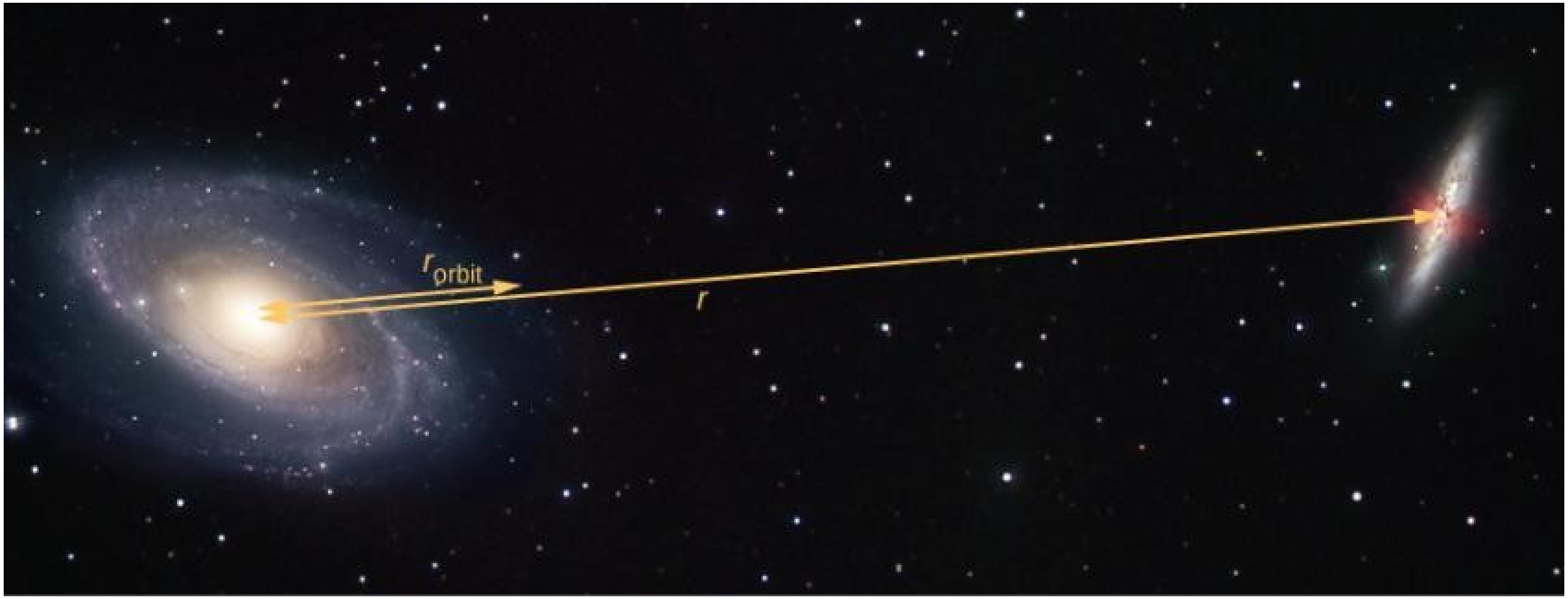
A satellite of mass *m* orbiting at radius *r* from the center of Earth. The gravitational force supplies the centripetal acceleration.

FIGURE 13.13



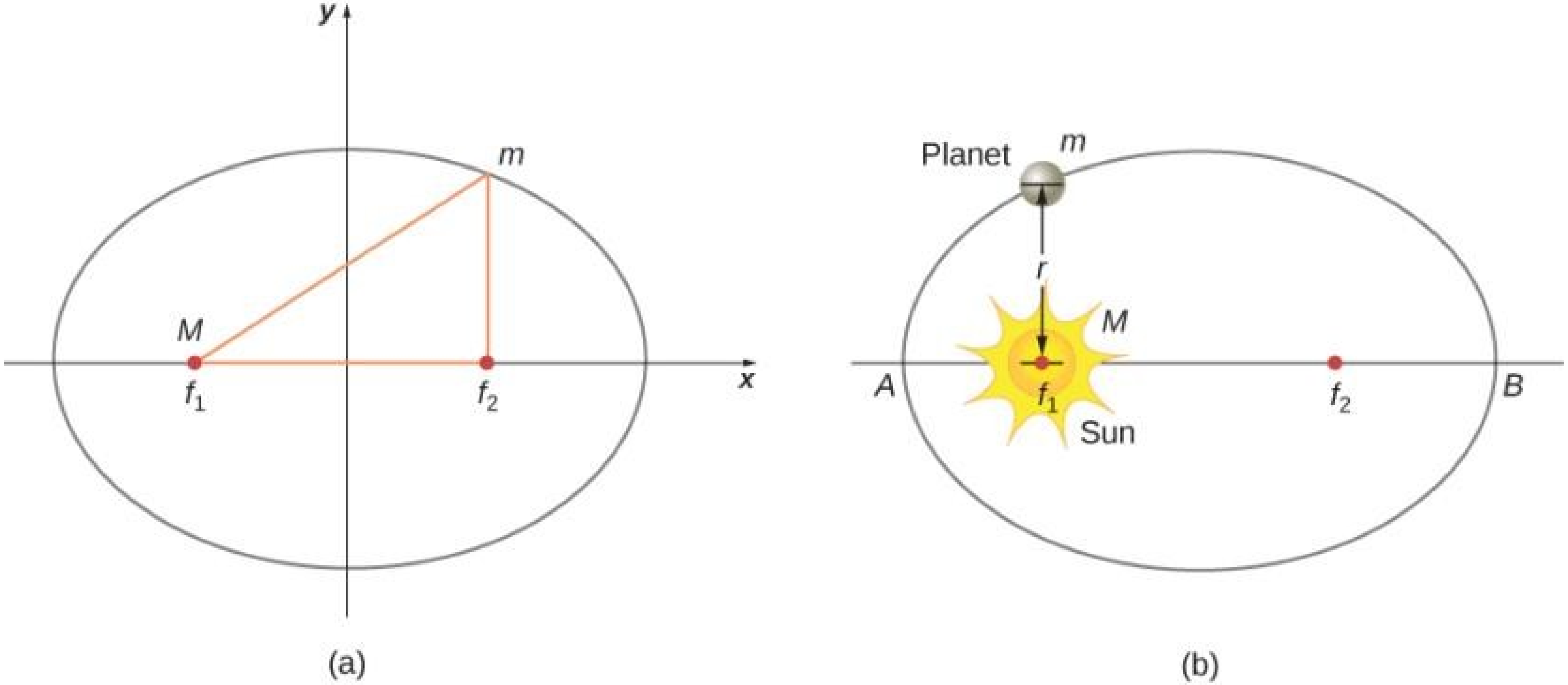
A circular orbit is the result of choosing a tangential velocity such that Earth's surface curves away at the same rate as the object falls toward Earth.

FIGURE 13.14



The distance between two galaxies, which determines the gravitational force between them, is r, and is different from r_{orbit}, which is the radius of orbit for each. For equal masses, $r_{orbit} = 1/2r$. (credit: modification of work by Marc Van Norden)

FIGURE 13.16

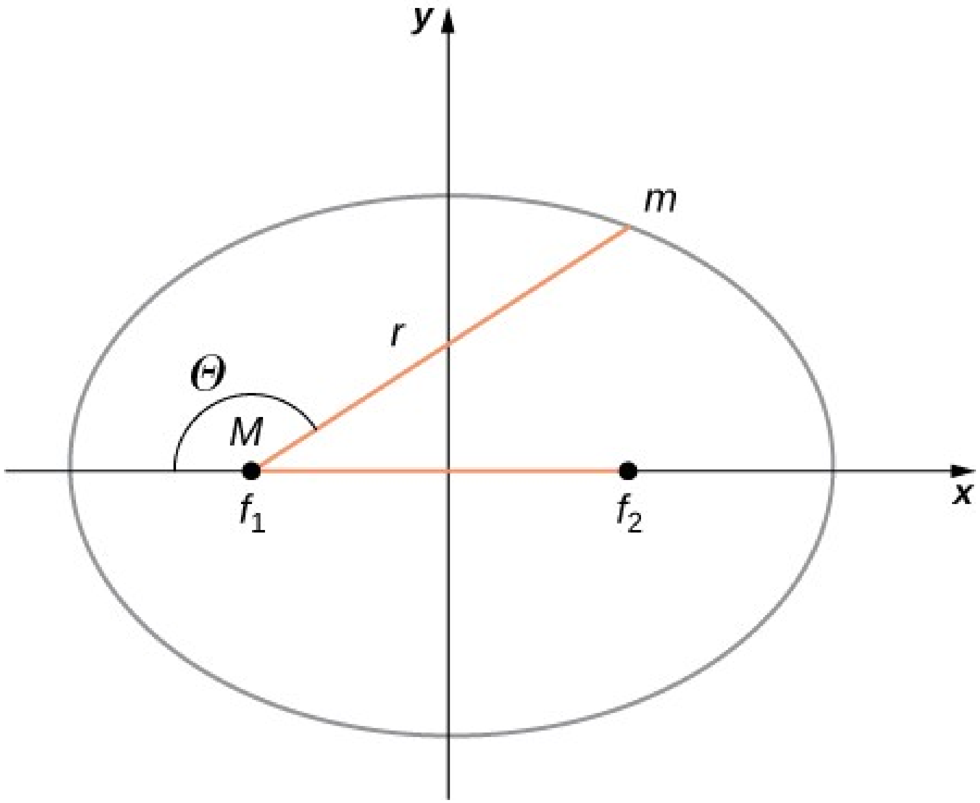


(a) An ellipse is a curve in which the sum of the distances from a point on the curve to two foci (f_1 and f_2) is a constant. From this definition, you can see that an ellipse can be created in the following way. Place a pin at each focus, then place a loop of string around a pencil and the pins. Keeping the string taught, move the pencil around in a complete circuit. If the two foci occupy the same place, the result is a circle—a special case of an ellipse.

(b) For an elliptical orbit, if m $\ll$ *M*, then *m* follows an elliptical path with *M* at one focus. More exactly, both *m* and *M* move in their own ellipse about the common center of mass.

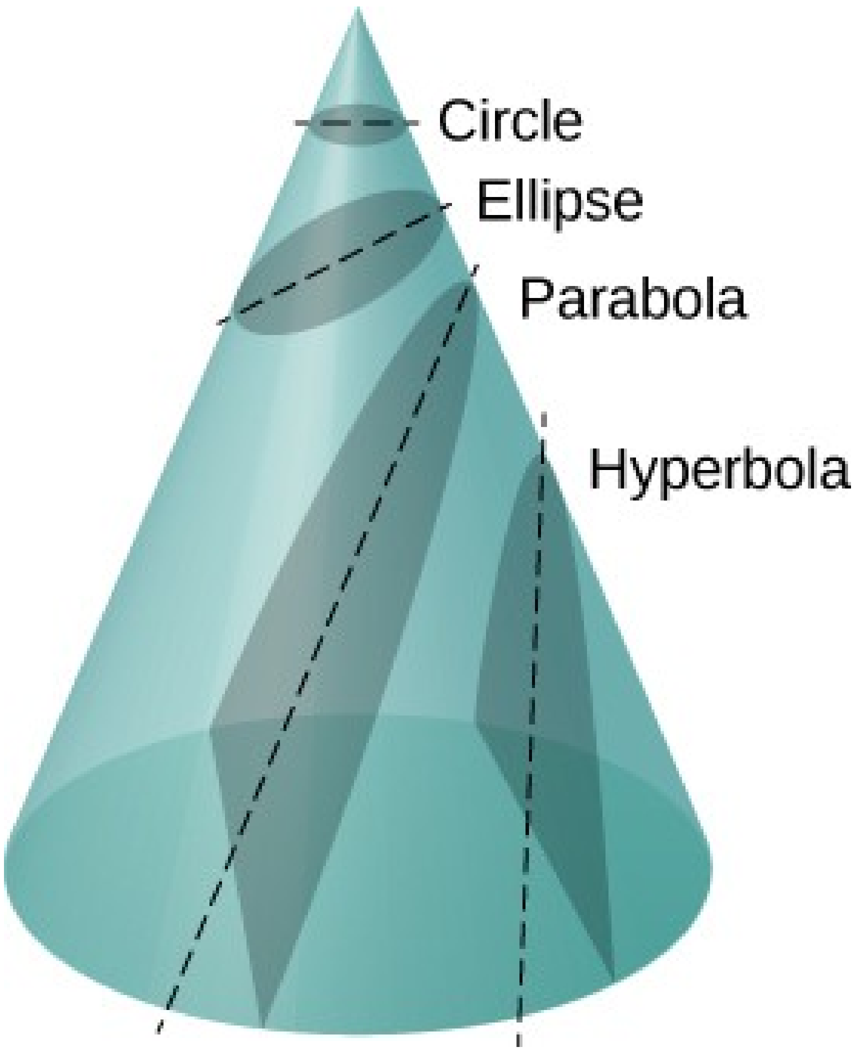
Kepler's first law states that every planet moves along an ellipse, with the Sun located at a focus of the ellipse.

FIGURE 13.17



As before, the distance between the planet and the Sun is *r*, and the angle measured from the *x*-axis, which is along the major axis of the ellipse, is θ.

FIGURE 13.18



All motion caused by an inverse square force is one of the four conic sections and is determined by the energy and direction of the moving body.

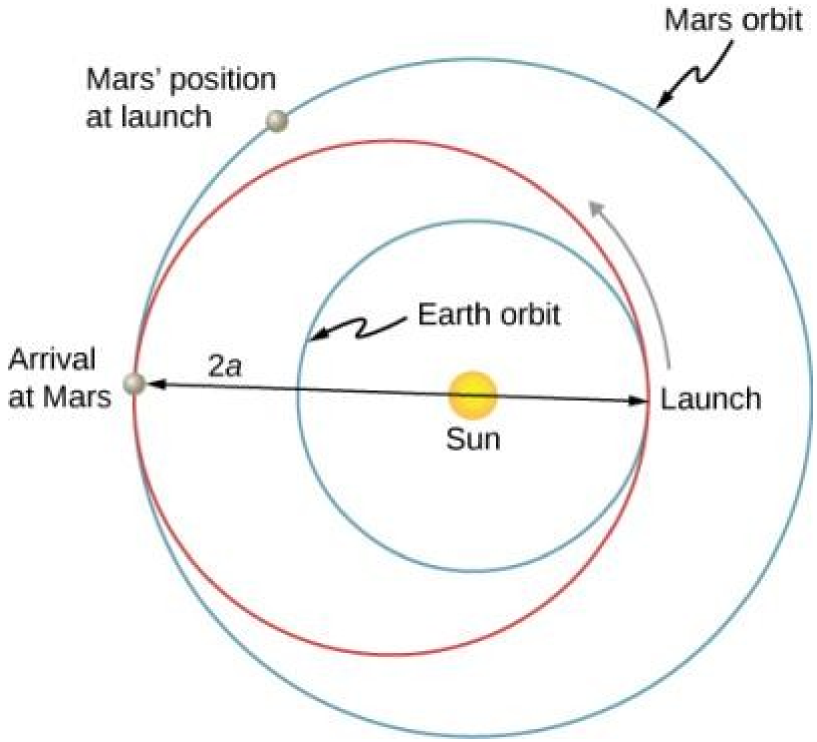
$$\frac{\alpha}{r} = 1 + e\cos\theta$$

e=0, E<0 circle

0<e<1, E<0 ellipse

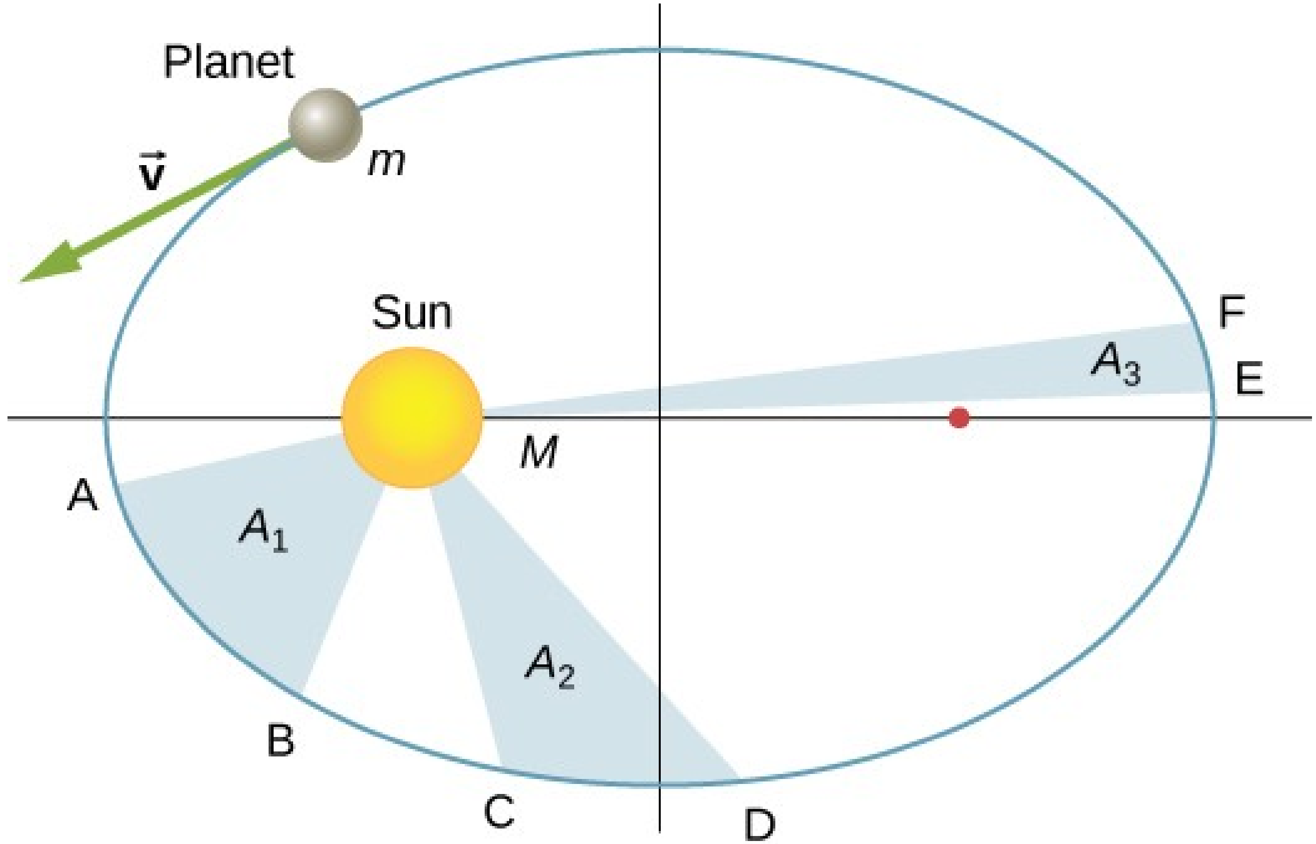
e=1, E=0 parabola
e>1, E>0 hyperbola

FIGURE 13.19



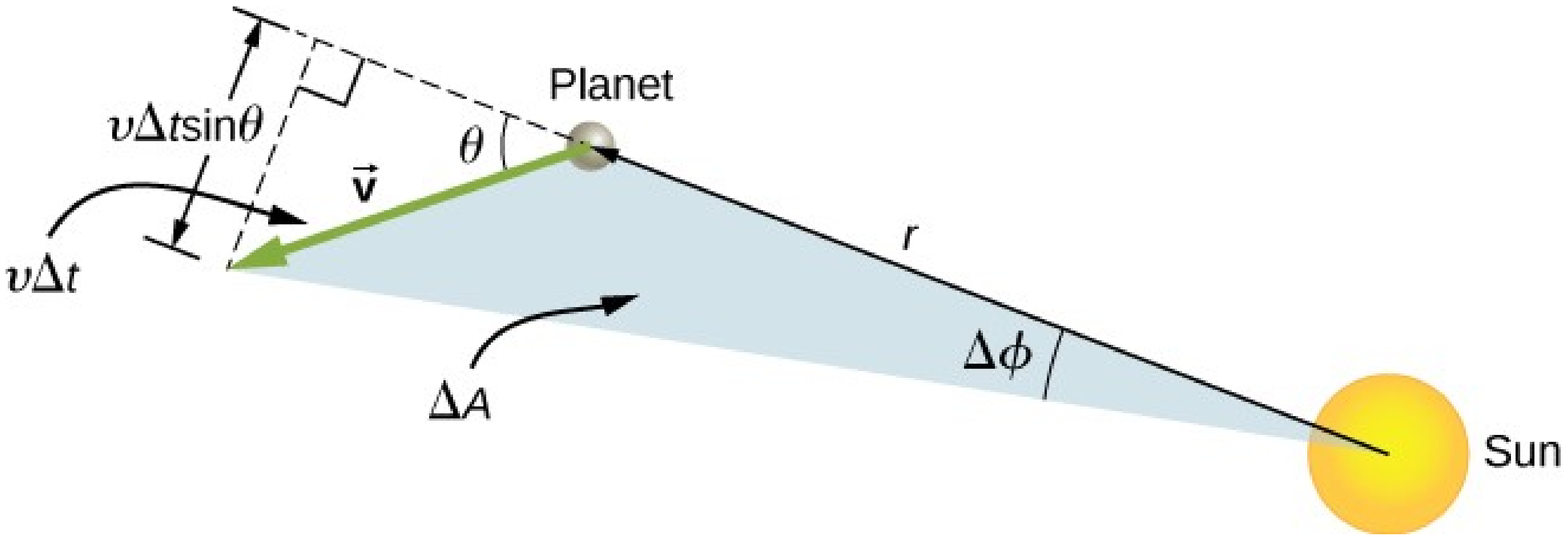
The transfer ellipse has its perihelion at Earth's orbit and aphelion at Mars' orbit.

FIGURE 13.20



The shaded regions shown have equal areas and represent the same time interval. **Kepler's second law** states that a planet sweeps out equal areas in equal times, that is, the area divided by time, called the areal velocity, is constant.

FIGURE 13.21



The element of area ΔA swept out in time Δt as the planet moves through angle $\Delta\phi$. The angle between the radial direction and is θ.

$$\vec{L} = m\vec{r}\times\vec{v}$$

$$L = mrv\sin\theta$$

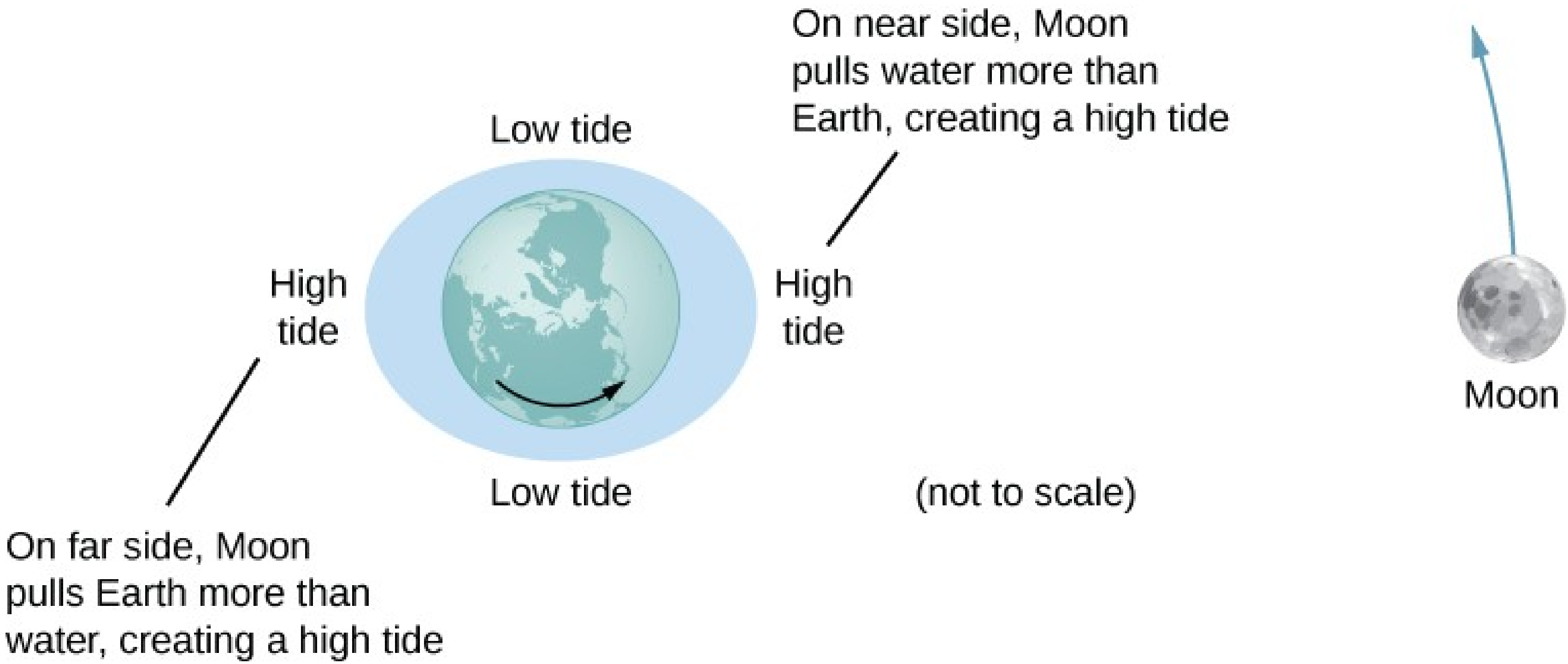
$$\Delta A = \frac{1}{2}lh = \frac{1}{2}vr\Delta t\sin\theta \rightarrow \frac{dA}{dt} = \frac{1}{2}vr\sin\theta = \frac{L}{2m}$$

Kepler’s third law

$$T^2 = \frac{4\pi^2}{GM} a^3$$

Tides

FIGURE 13.22



The tidal force stretches Earth along the line between Earth and the Moon. It is the *difference* between the gravitational force from the far side to the near side that creates the tidal bulge on both sides of the planet. Tidal variations of the oceans are on the order of few meters; hence, this diagram is greatly exaggerated.

FIGURE 13.23

The tidal force is the *difference* between the gravitational force at the center and that elsewhere. In this figure, the tidal forces are shown at the ocean surface. These forces would diminish to zero as you approach Earth's center.

FIGURE 13.24

(a and b) The spring tides occur when the Sun and the Moon are aligned, whereas (c) the neap tides occur when the Sun and Moon make a right triangle with Earth. (Figure is not drawn to scale.)

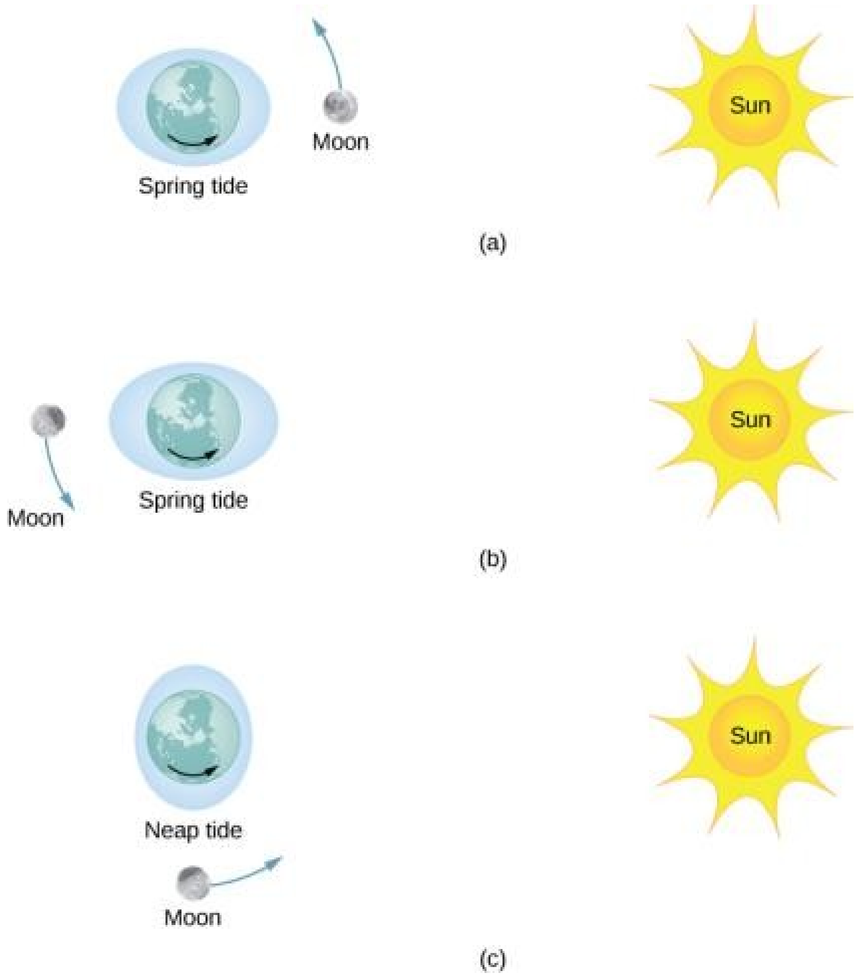


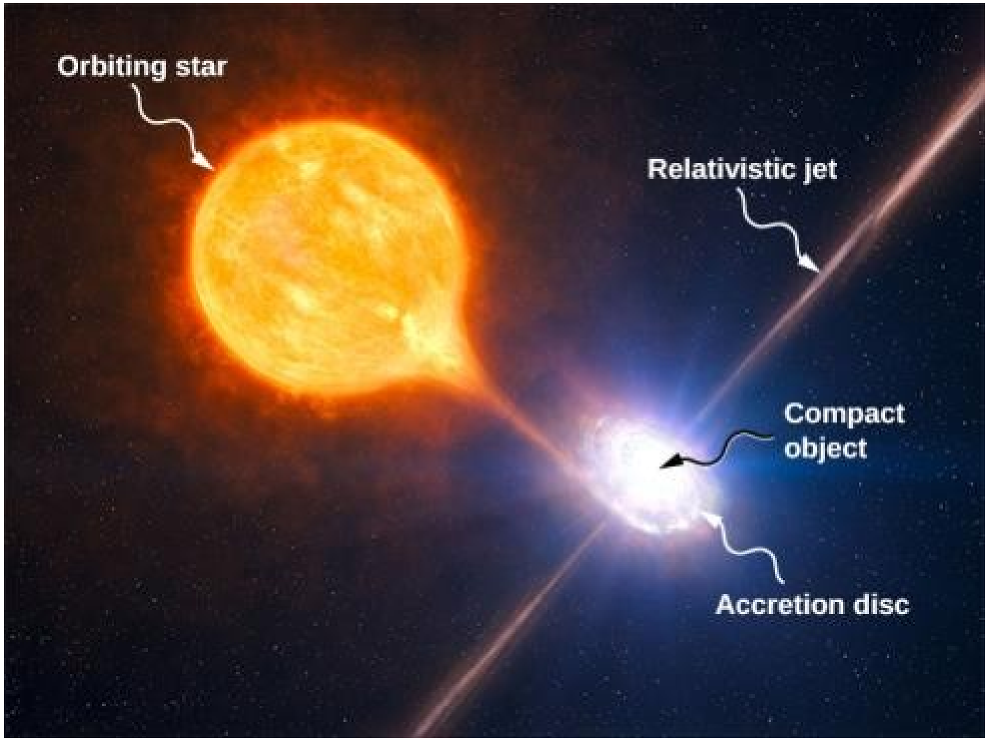
FIGURE 13.25

Boats in the Bay of Fundy at high and low tides. The twice-daily change in sea level creates a real challenge to the safe mooring of boats. (credit: Dylan Kereluk)

FIGURE 13.26

Dramatic evidence of tidal forces can be seen on Io. The eruption seen in blue is due to the internal heat created by the tidal forces exerted on Io by Jupiter.

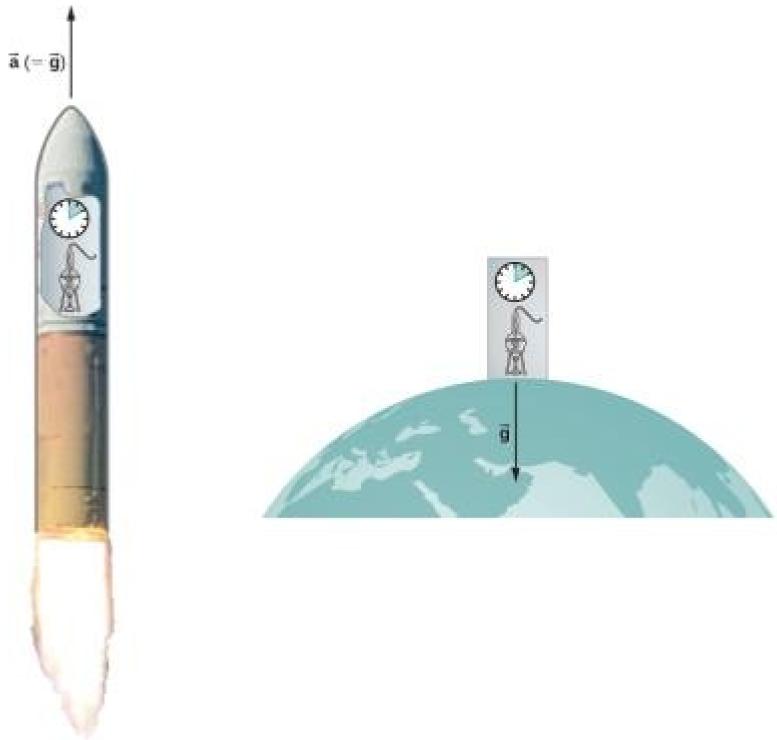
FIGURE 13.27



Tidal forces from a compact object can tear matter away from an orbiting star. In addition to the accretion disc orbiting the compact object, material is often ejected along relativistic jets as shown. (credit: modification of work by European Southern Observatory (ESO))

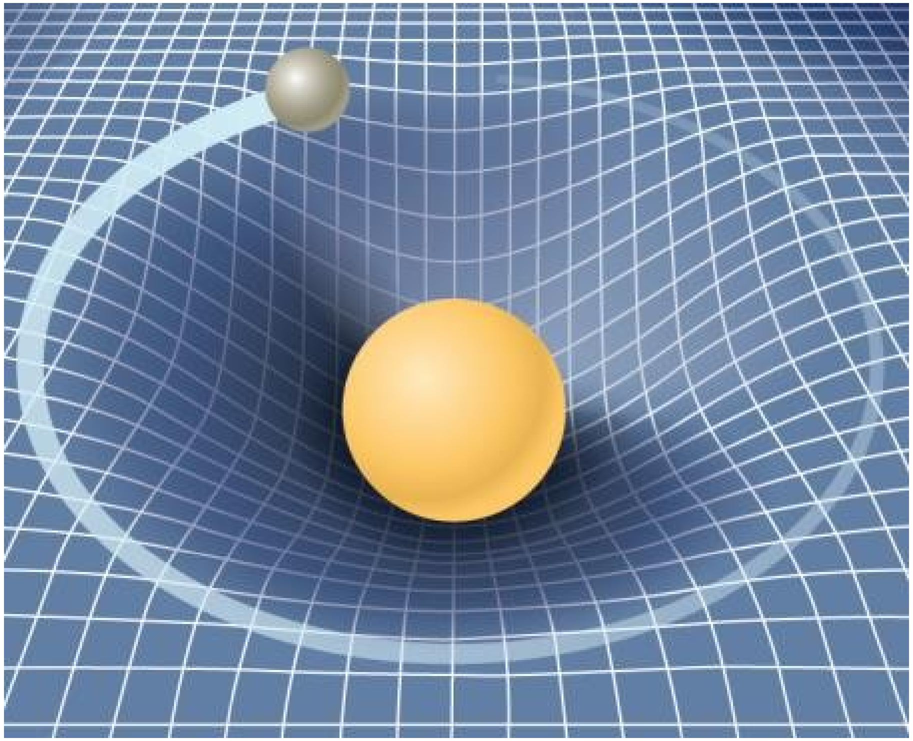
General relativity

FIGURE 13.28



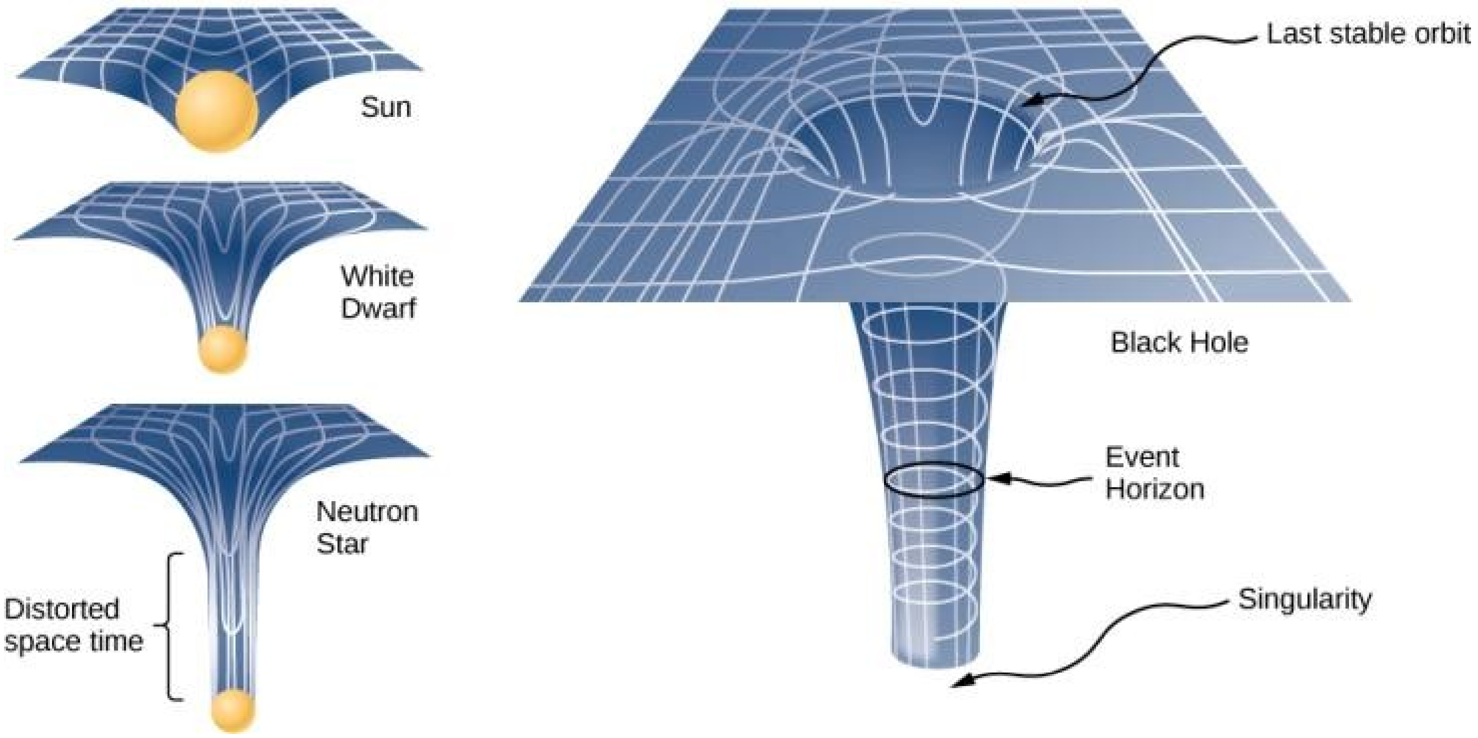
According to the principle of equivalence, the results of all experiments performed in a laboratory in a uniform gravitational field are identical to the results of the same experiments performed in a uniformly accelerating laboratory.

FIGURE 13.29



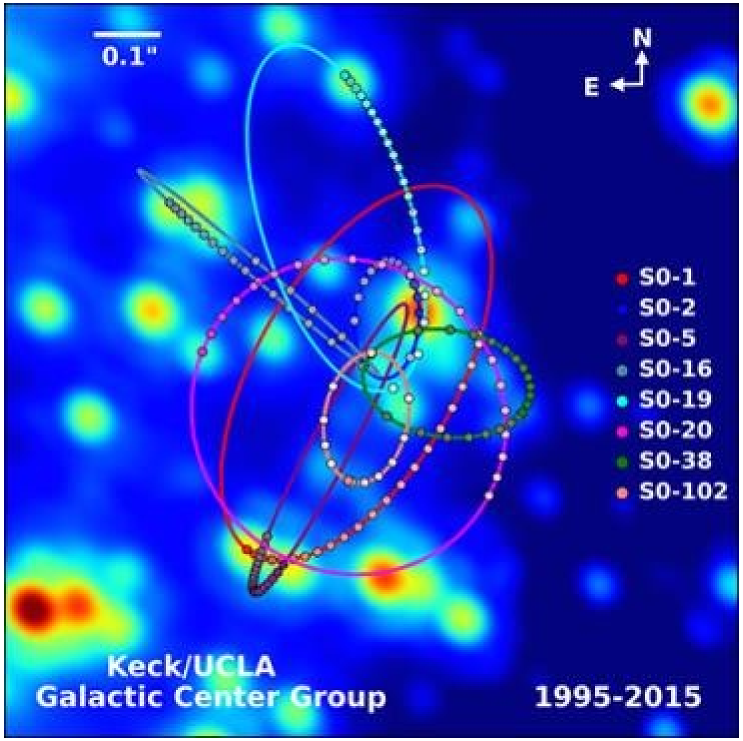
A smaller mass orbiting in the distorted space-time of a larger mass. In fact, all mass or energy distorts space-time.

FIGURE 13.30



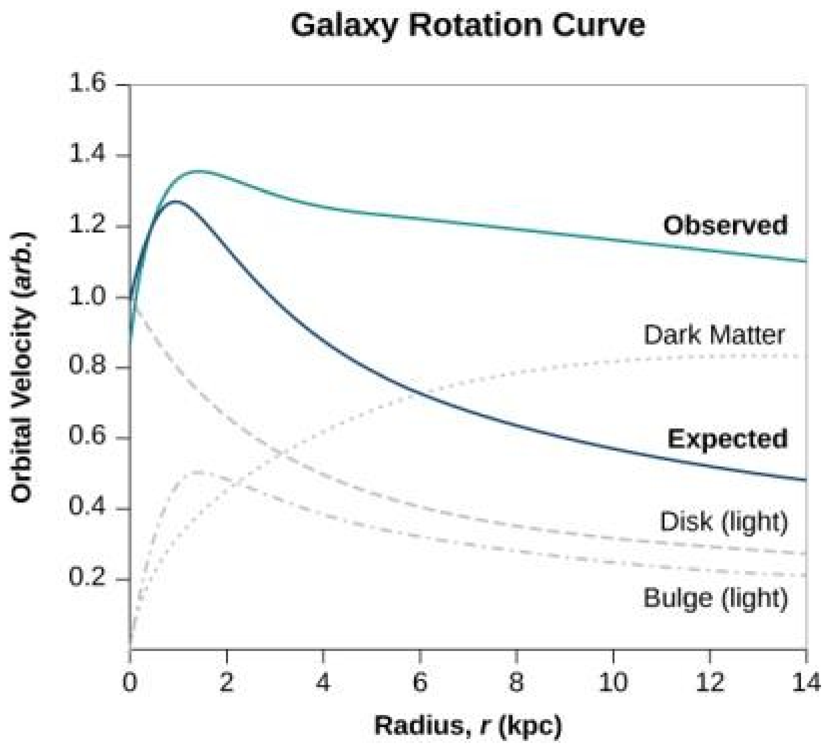
The space distortion becomes more noticeable around increasingly larger masses. Once the mass density reaches a critical level, a black hole forms and the fabric of space-time is torn. The curvature of space is greatest at the surface of each of the first three objects shown and is finite. The curvature then decreases (not shown) to zero as you move to the center of the object. But the black hole is different. The curvature becomes infinite: The surface has collapsed to a singularity, and the cone extends to infinity. (Note: These diagrams are not to any scale.)

FIGURE 13.31



Paths of stars orbiting about a mass at the center of our Milky Way galaxy. From their motion, it is estimated that a black hole of about 4 million solar masses resides at the center. (credit: UCLA Galactic Center Group – W.M. Keck Observatory Laser Team)

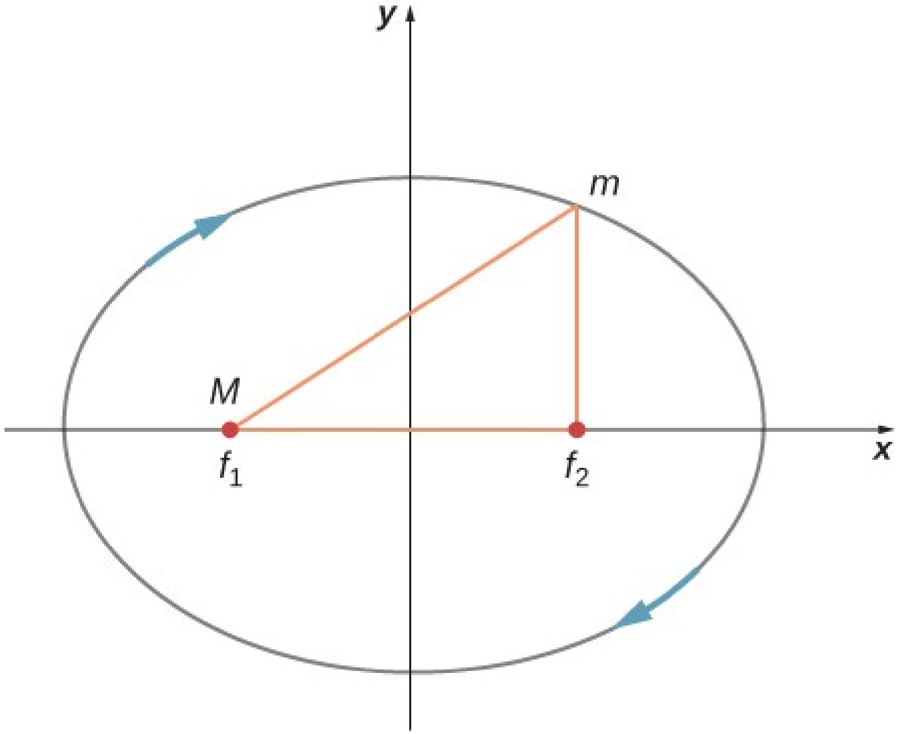
FIGURE 13.32



The blue curve shows the expected orbital velocity of stars in the Milky Way based upon the visible stars we can see. The green curve shows that the actually velocities are higher, suggesting additional matter that cannot be seen. (credit: modification of work by Matthew Newby)

Example

EXERCISE 9



In the diagram below for a satellite in an elliptical orbit about a much larger mass, indicate where its speed is the greatest and where it is the least. What conservation law dictates this behavior? Indicate the directions of the force, acceleration, and velocity at these points. Draw vectors for these same three quantities at the two points where the *y*-axis intersects (along the semi-minor axis) and from this determine whether the speed is increasing decreasing, or at a max/min.