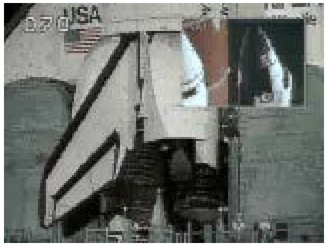
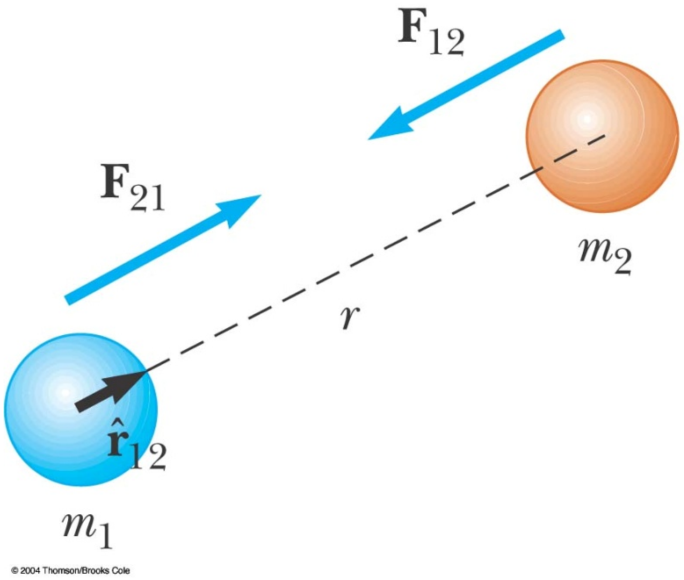
Newton’s Universal Law of Gravitation



Law of Gravitation

- $\mathbf{F}_{12} = -\mathbf{F}_{21}$

$$F_g = G\frac{m_1 m_2}{r^2}$$



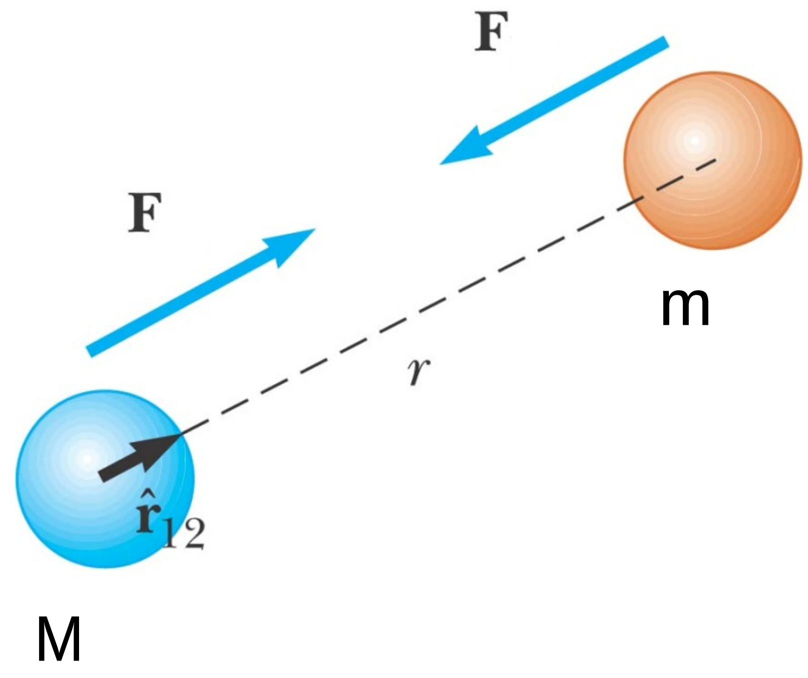
G is the ***universal gravitational constant*** and equals **6.673 x 10^{-11}** N·m^2 / kg^2

Law of Gravitation

$$F_g = G\frac{mM}{r^2}$$

$$mg = G\frac{mM}{r^2}$$

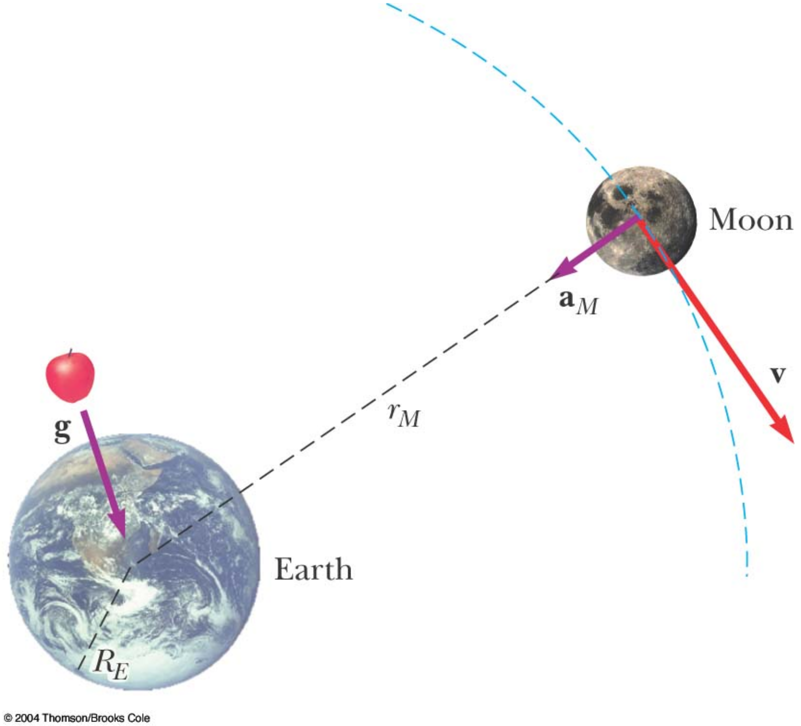
$$\Rightarrow g = G\frac{M}{r^2}$$



G is the ***universal gravitational constant*** and equals **6.673 x 10⁻¹¹** N·m^2 / kg^2

Centripetal Acceleration

$$\mathbf{g} \equiv \frac{\mathbf{F}_g}{m}$$



$$9.8\ m/s^2 \text{ at sea level}$$

Variation of *g* with Height

Altitude h (km)	g (m/s^2)
1 000	7.33
2 000	5.68
3 000	4.53
4 000	3.70
5 000	3.08
6 000	2.60
7 000	2.23
8 000	1.93
9 000	1.69
10 000	1.49
50 000	0.13
∞	0

Kepler’s Laws: Introduction

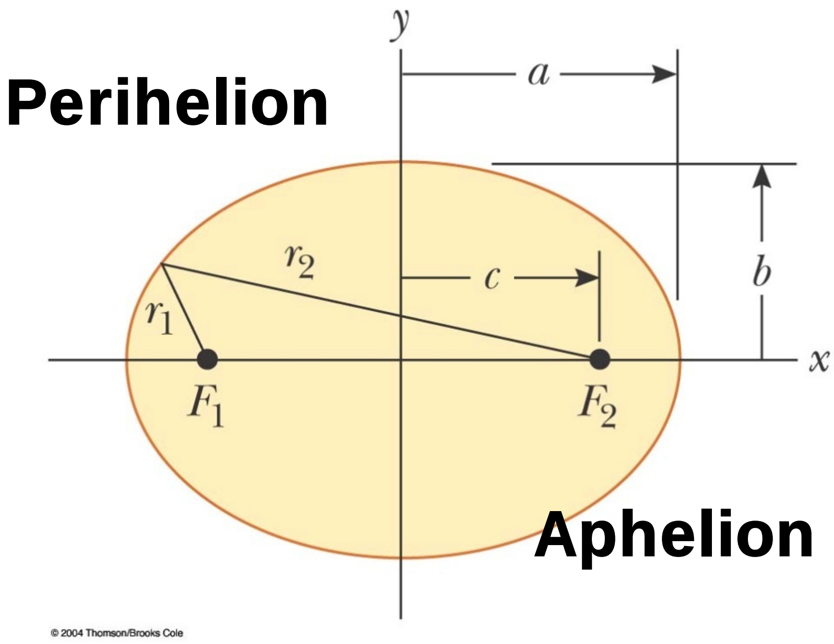
- Johannes Kepler was a German astronomer
- He was Tycho Brahe’s assistant
  - Brahe was the last of the “naked eye” astronomers
- Kepler analyzed Brahe’s data and formulated three laws of planetary motion

Kepler’s Laws

- Kepler’s First Law
  - All planets move in elliptical orbits with the Sun at one focus
- Kepler’s Second Law
  - The radius vector drawn from the Sun to a planet sweeps out equal areas in equal time intervals
- Kepler’s Third Law
  - The square of the orbital period of any planet is proportional to the cube of the semimajor axis of the elliptical orbit

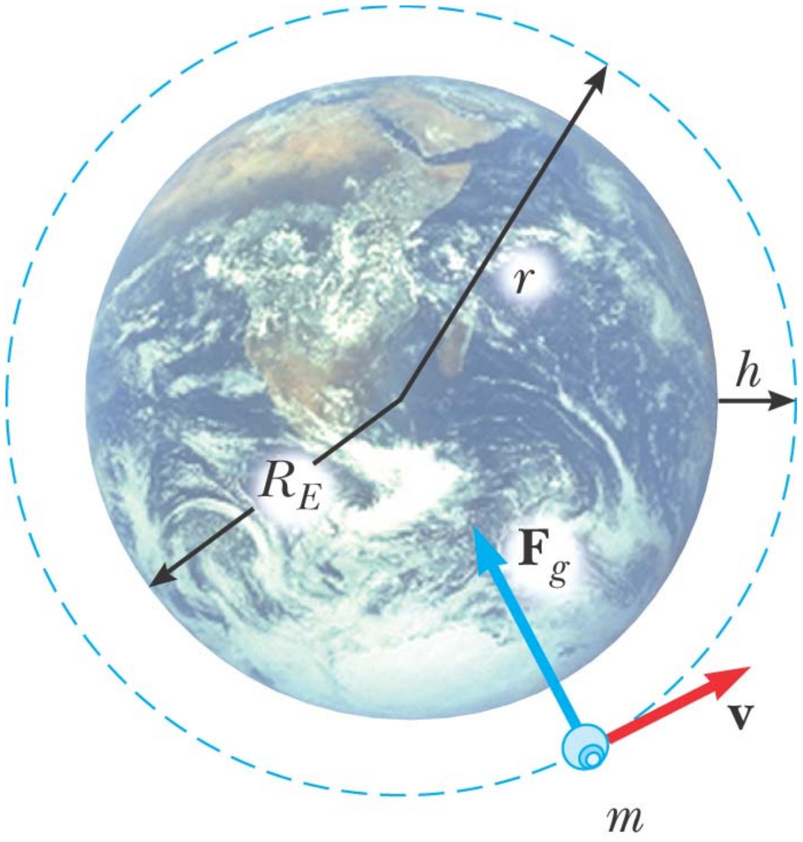
Notes About Ellipses

- F_1 and F_2 are each a **focus** of the ellipse
  - They are located a distance *c* from the center
- The longest distance through the center is the **major axis**
  - *a* is the *semimajor axis*



Example, Geosynchronous Satellite

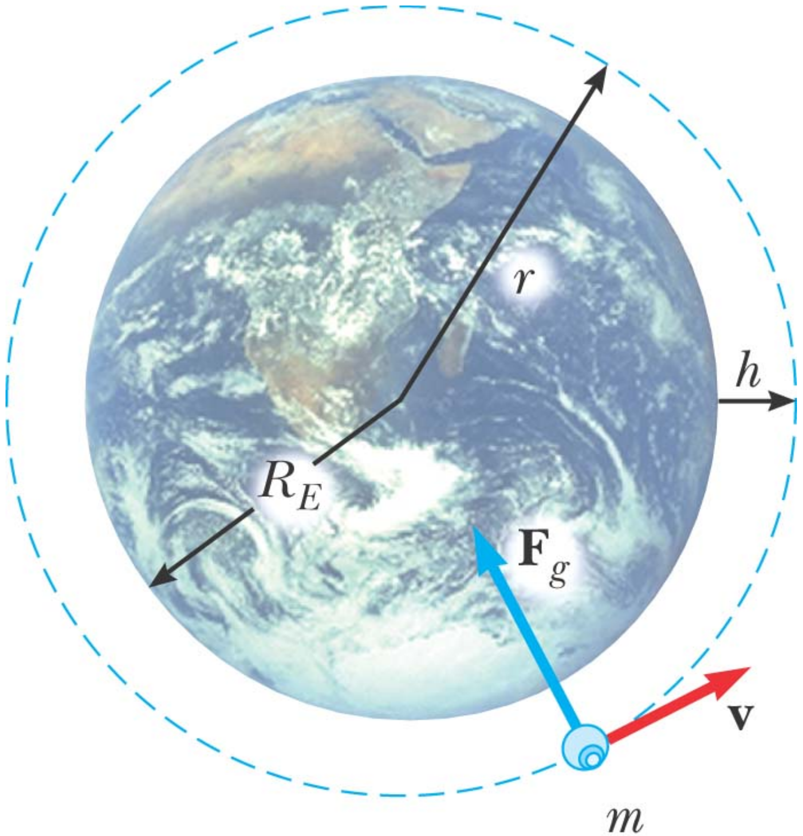
- A geosynchronous satellite appears to remain over the same point on the Earth



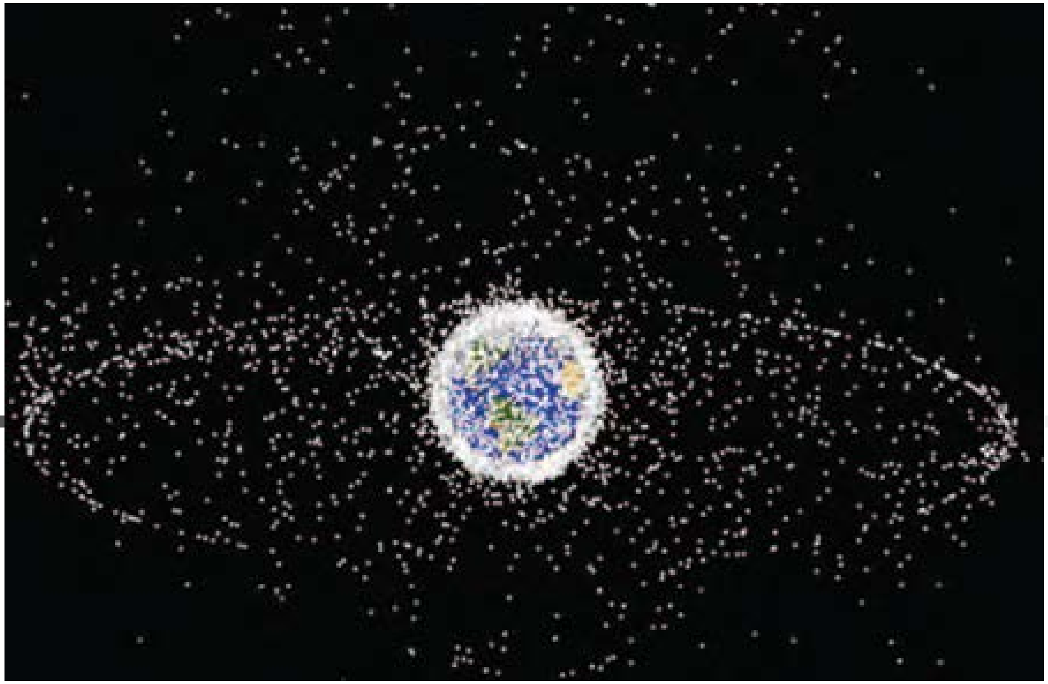
Example, Geosynchronous Satellite

$$G\frac{mM}{r^2} = m\frac{v^2}{r} \therefore v = \sqrt{\frac{GM}{r}}$$

$$v = \frac{2\pi r}{T} \Rightarrow r^3 = \frac{GM}{4\pi^2}T^2$$



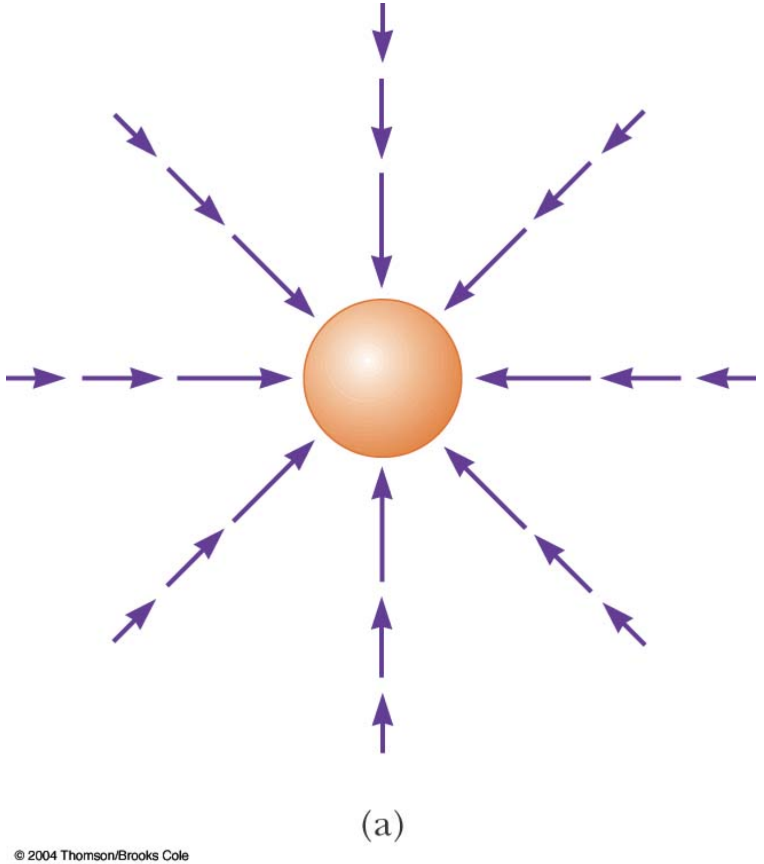
Crowded Sky: **From U.S. Space, NORAD**



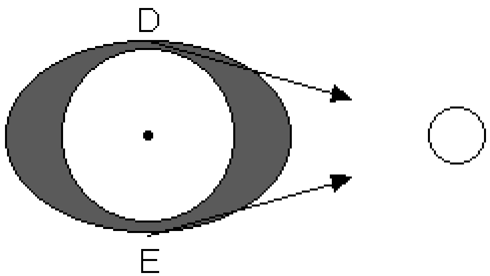
Many artificial satellites have been placed in orbit about the Earth. This diagram shows a plot of all known unclassified satellites and satellite debris larger in size than a baseball. Note the large number of **geosynchronous** satellites that form a visible circle above the Earth's equator.

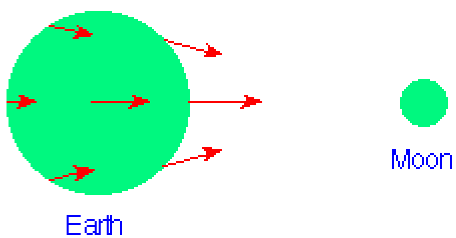
The Gravitational Field

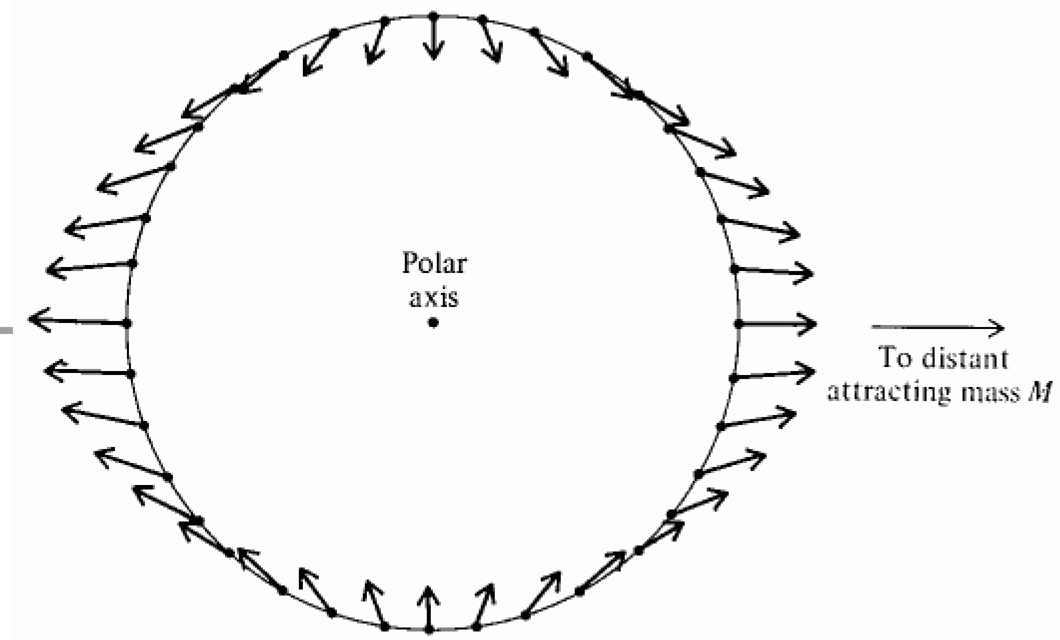
- The gravitational field vectors point in the direction of the acceleration a particle would experience if placed in that field
- The magnitude is that of the freefall acceleration at that location

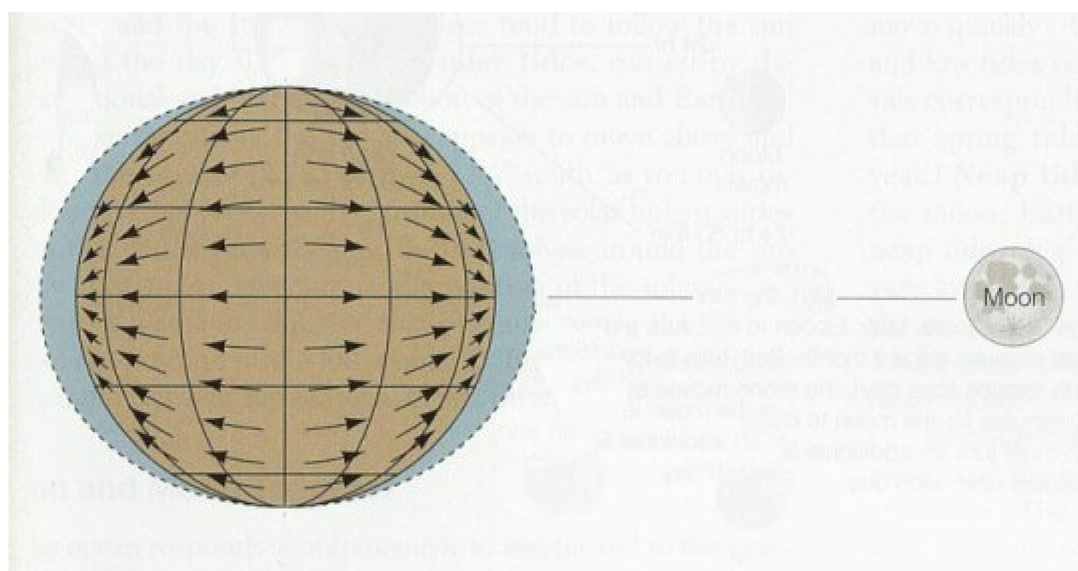


Tides



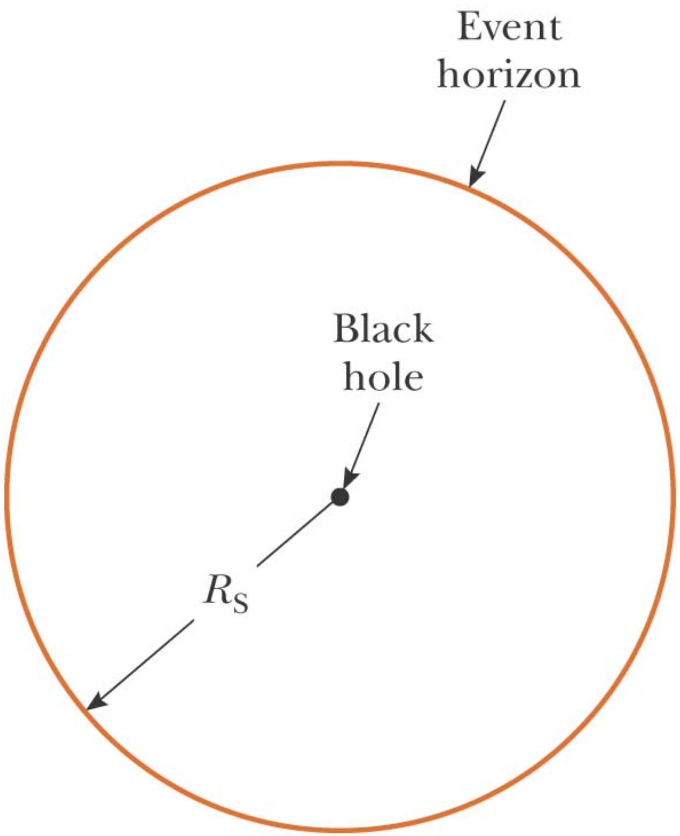






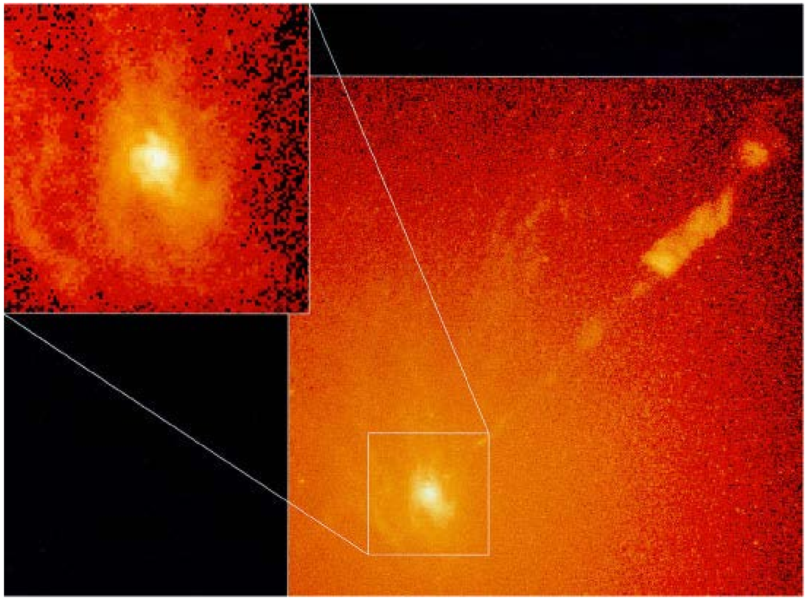
Black Holes

- The critical radius at which the escape speed equals *c* is called the **Schwarzschild radius**, R_S
- The imaginary surface of a sphere with this radius is called the **event horizon**
  - This is the limit of how close you can approach the black hole and still escape



Black Holes at Centers of Galaxies

- There is evidence that supermassive black holes exist at the centers of galaxies
- Theory predicts jets of materials should be evident along the rotational axis of the black hole



- *An HST image of the galaxy M87. The jet of material in the right frame is thought to be evidence of a supermassive black hole at the galaxy's center.*