1 Understanding Gravity

1.1 Aristotle

Aristotle, 384 – 322 B.C.

Plato and Aristotle

Motion in the Solar System Earth was the center of the universe - *Geocentric*

Sun and planets orbited Earth in perfect circles

Sun and planets orbited at constant speed

Held in place by crystal spheres

If the Sun was the center of the solar system then we should observe parallax of the stars

Motion on Earth Heavy objects fall faster than light objects

Objects fall at constant speed

Natural motions - falling objects

Violent motions - pulling a wagon

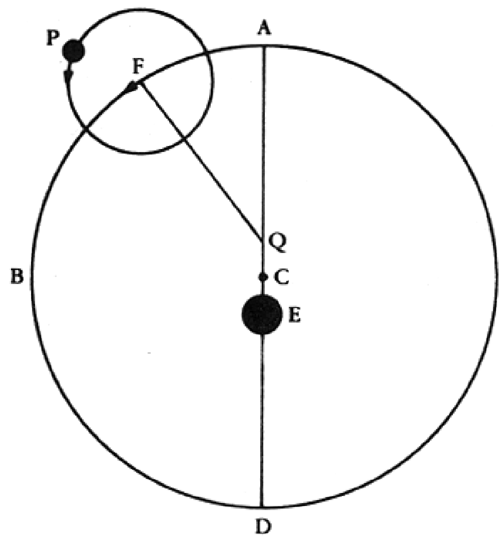
1.2 Ptolmey

Ptolemy [Claudius Ptolemaeus], c. 100 – 178 A.D.

Motion in the Solar System Earth still at the center of the universe

Most planets moved on epicycles

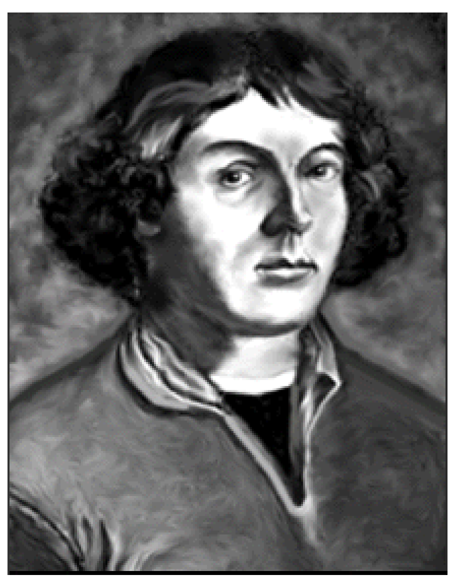
Epicycles orbited Earth on deferent



This was used to try and explain retrograde motion
Too complicated

1.3 Copernicus

Nicholas Copernicus, 1473 – 1543



Motion in the Solar System Sun at the center of solar system - *Heliocentric*
Earth orbits Sun

Planets still move in perfectly circular orbits at constant speed

1.4 Kepler

Johannes Kepler, 1571 – 1630

Motion in the Solar System Stole Tycho Brahe's data

Discovered the 3 laws of planetary motion

- Planets move around Sun in elliptical orbits - *Ellipses*
- Radius vector sweeps out equal areas in equal times
  - Planet moves fastest when it's near the sun and slower when it's farther away
- The square of the period of a planet is proportional to the cube of the average distance from Sun
  - $P^2 \propto a^3$

Believed the planets were pushed around Sun by angels - 1615

Up until this time no one had taken a serious look at gravity

1.5 Galileo

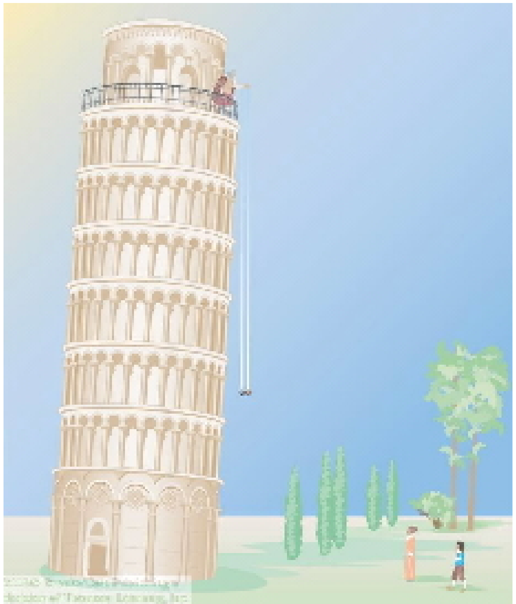
Galileo Galilei, 1564 – 1642

Motion on Earth First true modern scientist

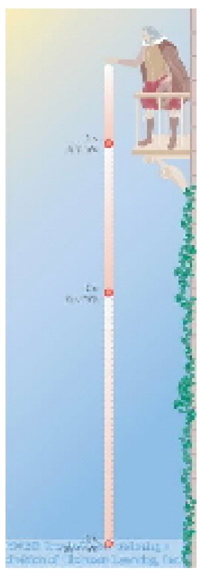
Performed experiments

Made measurements

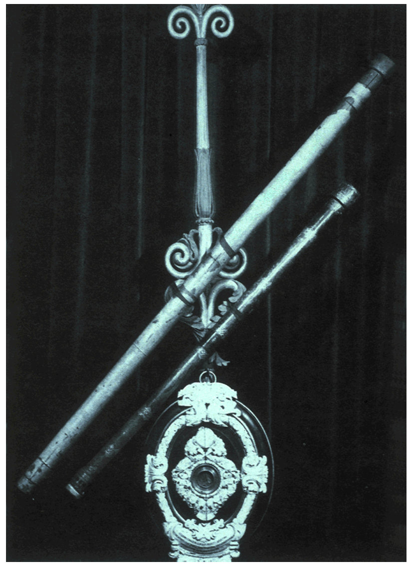
Dropped two balls off Leaning Tower of Pisa

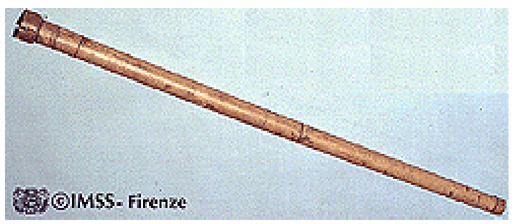


All objects fall at the same rate, independent of weight
Objects accelerate from rest at the rate of $\mathsf{g} = 9.80\,\mathrm{m/s^2} = 32.2\,\mathrm{ft/s^2}$



Discovers the Law of Inertia
Uses the newly discovered telescope to look at the heavens





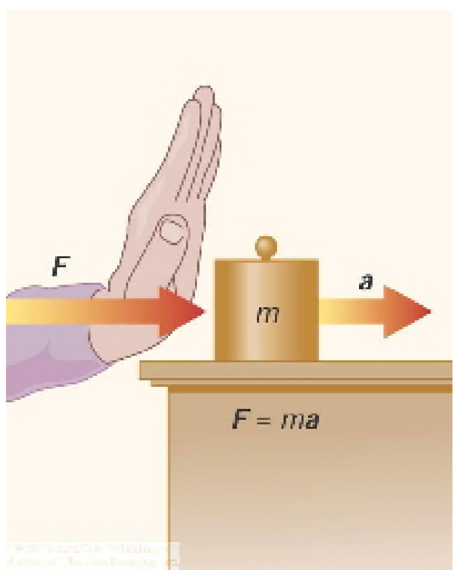
Discovers the 4 large satellites of Jupiter
Sees mountains and craters on Moon
Sees the rings of Saturn but doesn't know what they are

1.6 Newton

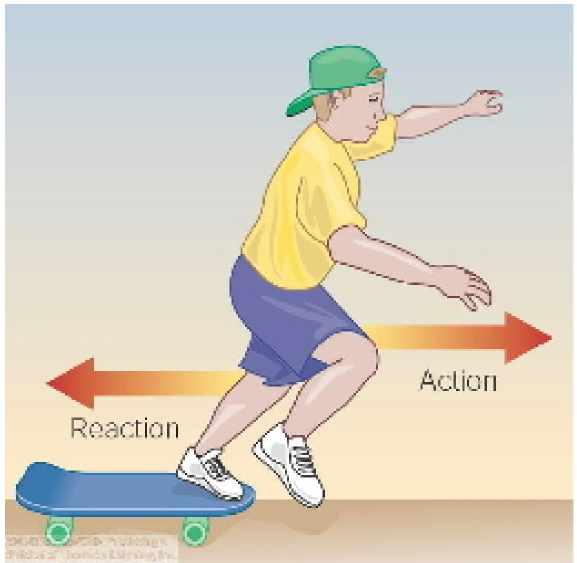
Sir Isaac Newton, 1642 – 1727

Motion on Earth   Newton's 3 laws of motion

- Law of Inertia
- $F = ma$



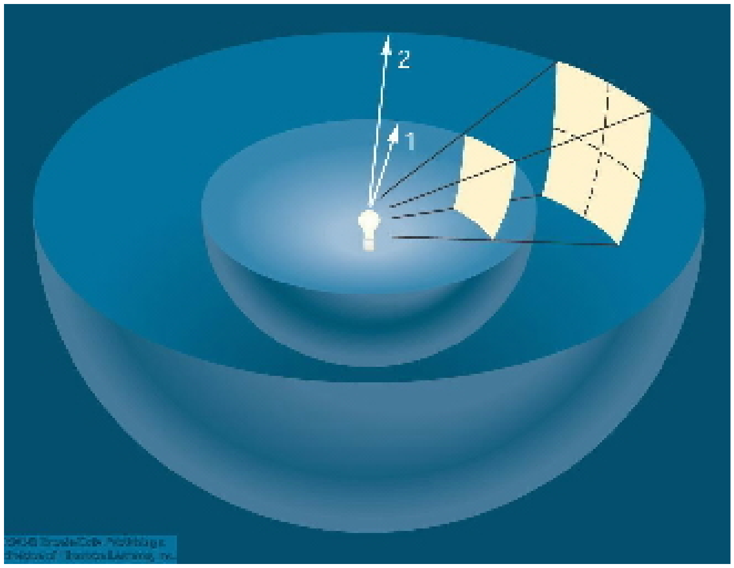
- Action - Reaction Law

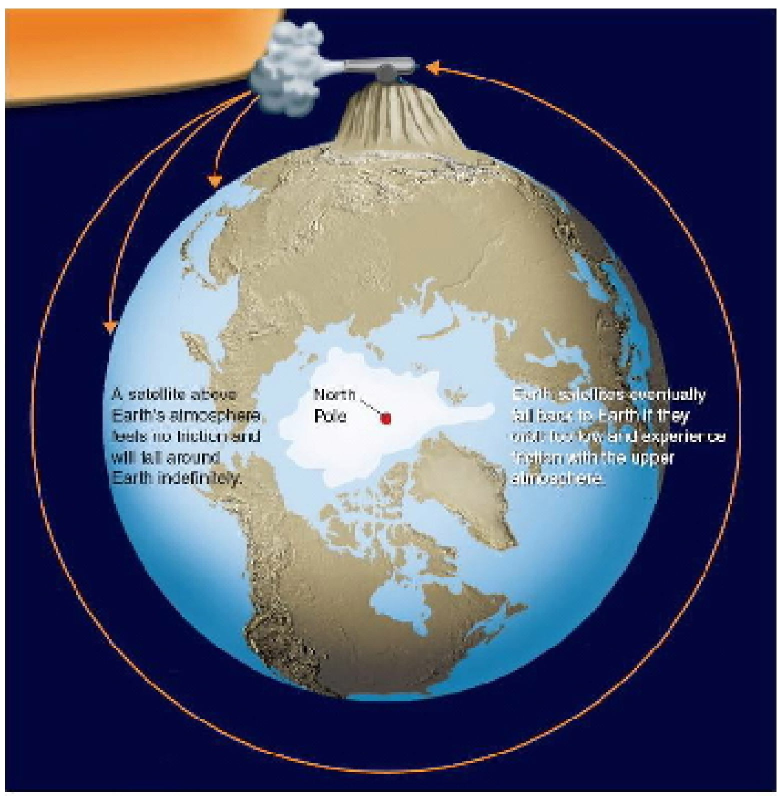


You can change a particle's velocity by changing its speed, its direction or both.

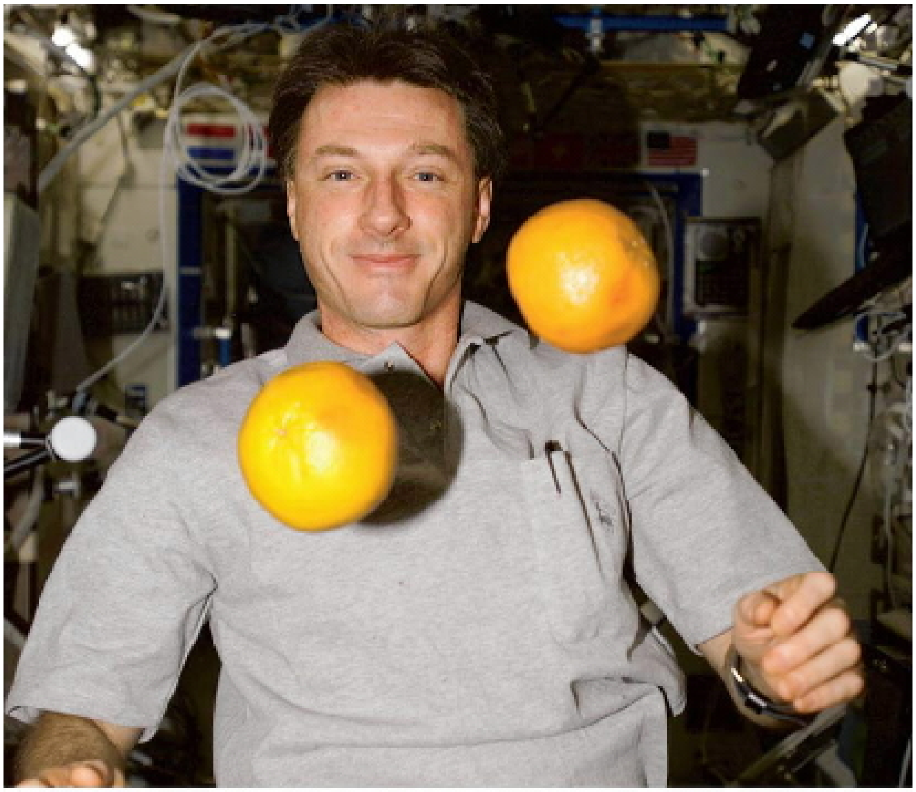
- Linear acceleration is a slowing down or speeding up, hence changing the magnitude of its velocity. This acceleration is parallel or antiparallel to the direction of motion (along the direction of motion).
- Centripetal acceleration is a turning. This acceleration is perpendicular to the directiton of motion, the object is turning and changing its direction of motion.

Momentum of an object depends on mass and velocity
A force produces a change in momentum
A force was needed to pull the Moon out of straight line motion, i.e., change the Moon's momentum
Gravity is a force
The gravitational force between two masses: $F = -\frac{GMm}{r^2}$
G is the gravitational constant, $G = 6.67259 \times 10^{-11}\,\mathrm{N\,m^2/\,kg^2}$
Gravity always attracts
Inverse square law





Now we envision a *gravitational field* surrounding Earth



Gravity is the weakest of the 4 fundamental forces of nature

1.6.1 Orbital Moiton

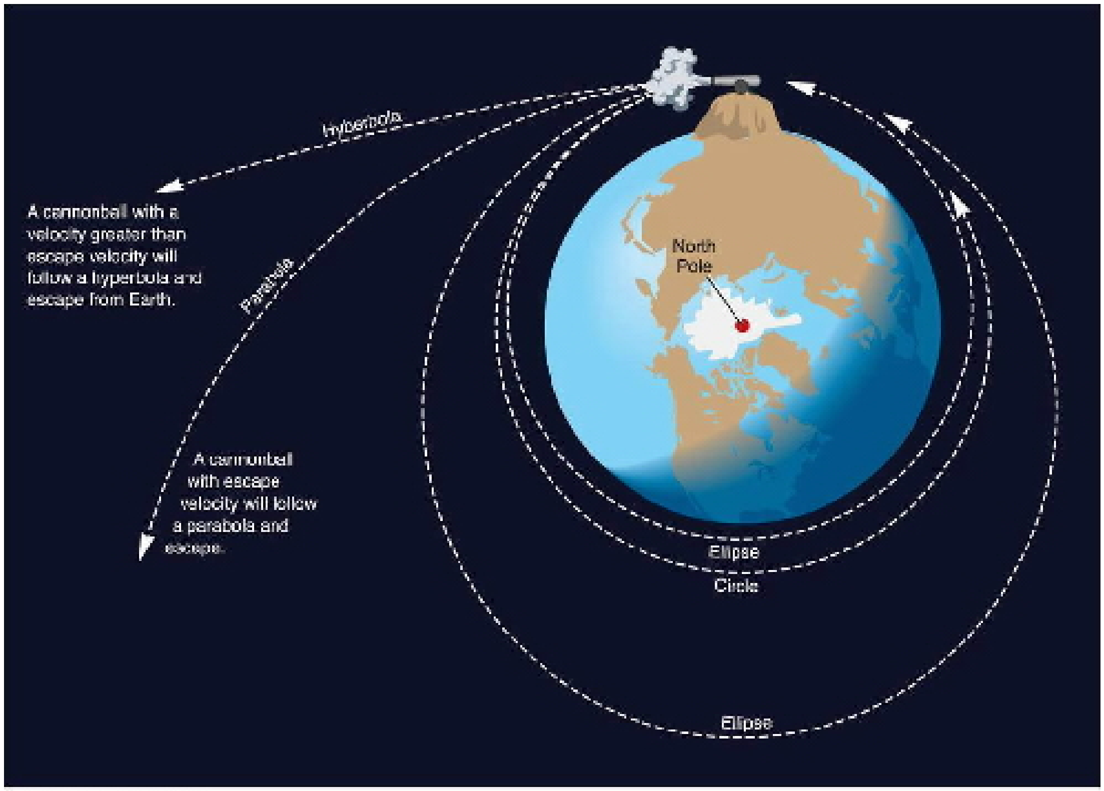
The gravitational force results in a centripetal acceleration

$$F_G = \frac{GMm}{r^2} = m\frac{v^2}{r}$$

Solving for v we get the circular velocity

$$v_c = \sqrt{\frac{Gm}{r}}$$

Geosynchronous orbits - period equals 24 hours
Open and closed orbits



Properties of the ellipse

Derivation of Kepler's Third Law - $P^2 = \frac{4\pi^2}{GM}a^3$

1.7 Einstein

Albert Einstein, 1882 - 1955

1912

1933

Brownian Motion - 1905

- Evidence of the molecular stucture of matter

Photoelectric Effect - 1905

- Light comes in the form of particles

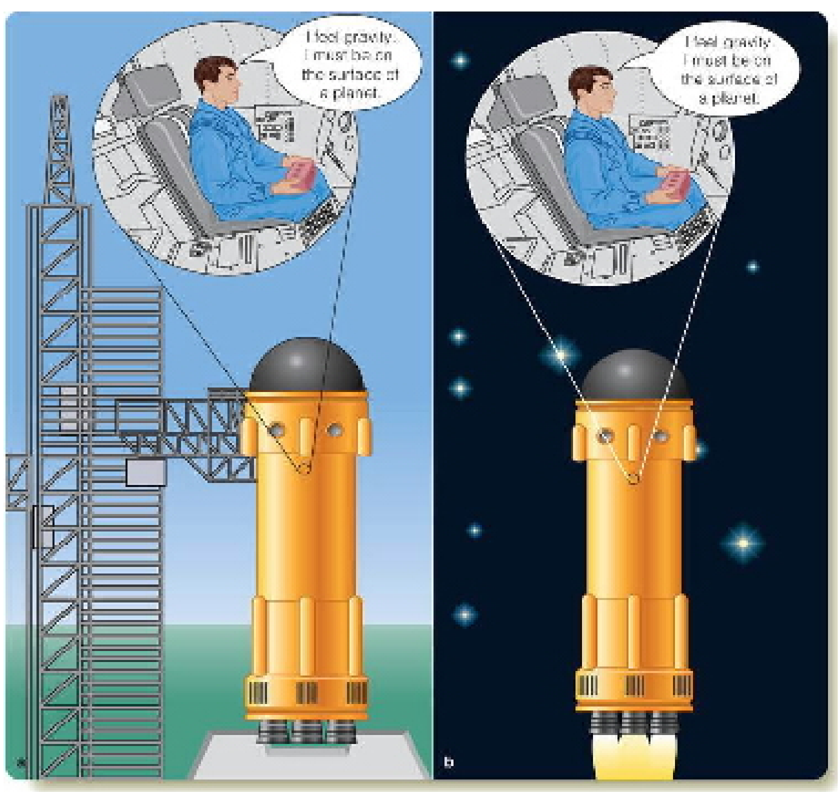
Special Relativity - 1905

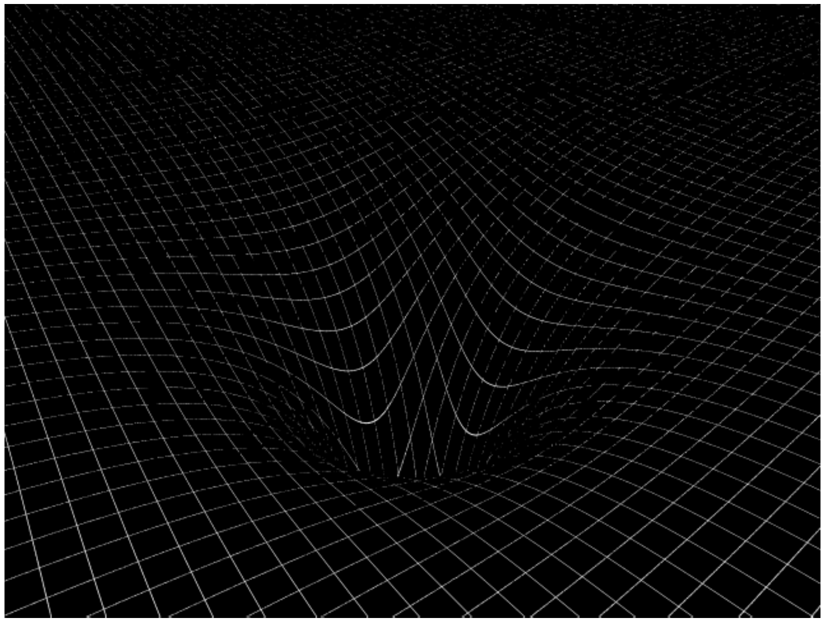
- Describes motion at speeds close to the speed of light
- Time passes by differently for different observers, depends on their relative motion

- Lengths are measured differently for different observers
- Accelerations are not allowed
  - First Postulate (the principle of relativity) - The laws of physics are the same for all observers, no matter where their motion so long as they are not accelerated
  - Second Postulate - The velocity of light is constant and will be measured to be the same for all observers independent of their motion

General Relativity - 1915

- Space and time are connected - Space-time
- Requires 4 dimensions
- Takes into account accelerations
  - Equivalence Principle - Inertial forces due to accelerations and gravitational forces due to a massive body can not be distinguished by a local observer





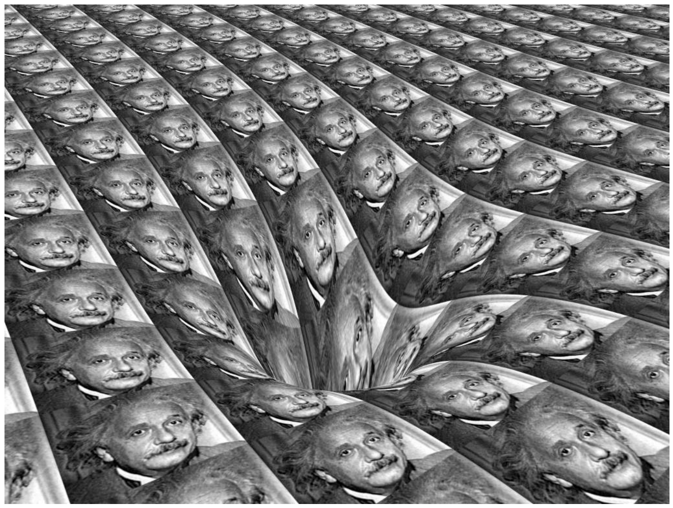
- Space-time is curved by masses
- Space-time tells matter how to move
- Matter tells space-time how to curve

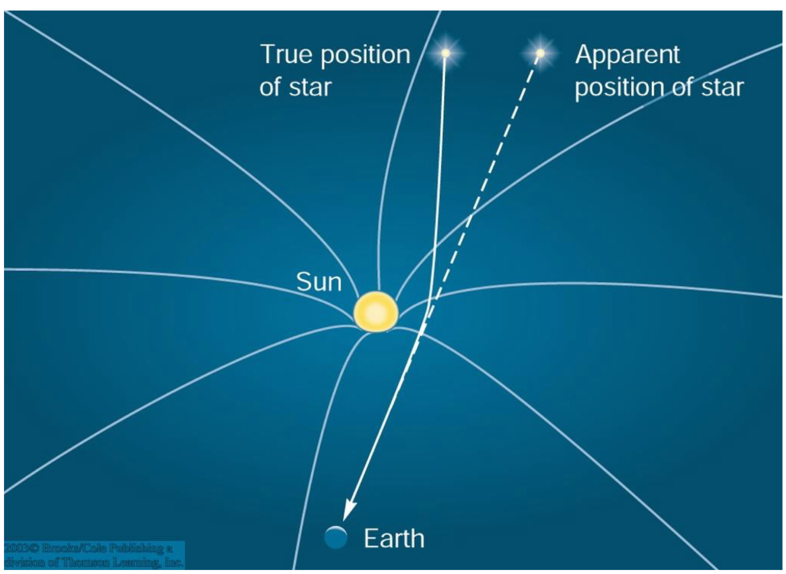
Noble Prize - 1921, Photoelectric Effect

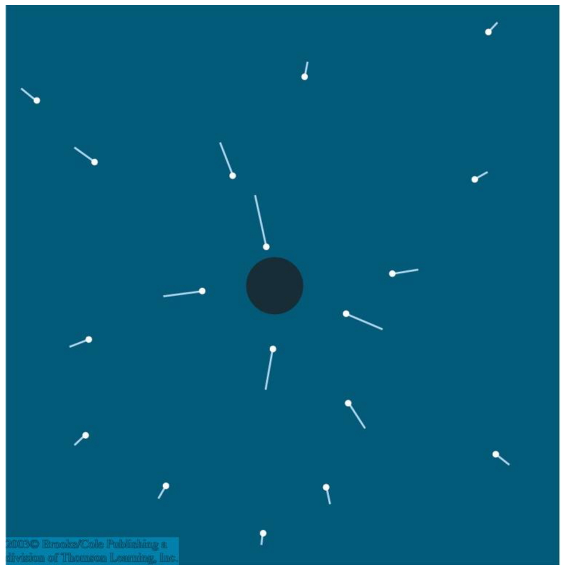
Einstein spent the rest of his life trying to understand the fundamental properties of matter.

Testing general relativity

- Bending of light around the Sun
- Prescession of Mercury's perihelion




True position
of star
Apparent
position of star
Sun
Earth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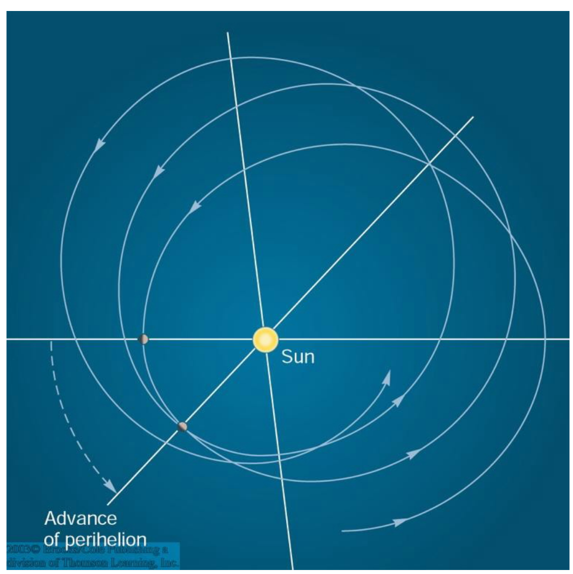
Sun
Advance
of perihelion
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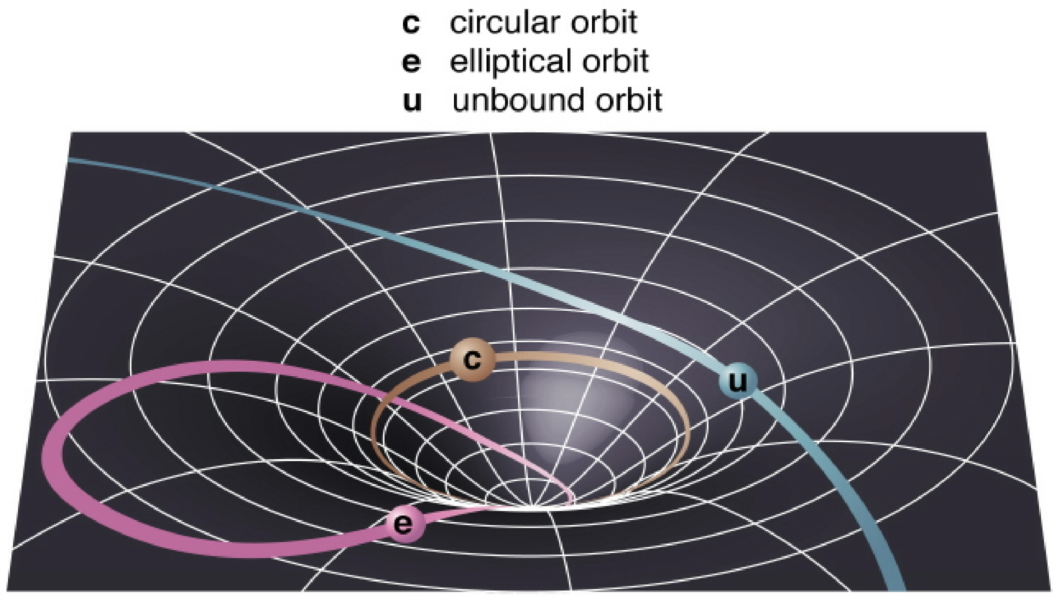
c circular orbit
e elliptical orbit
u unbound orbit
c
u
e