

Lecture #14 Tues Mar 16 General Relativity

History of gravity and motion of the planets

Aristotle/Ptolemy: circles

Kepler: ellipses

Newton: general theory of celestial orbits

Aristotle: planets must move in circles

Problem with retrograde motion of planets; Ptolemy (85-165) added “epicycles”
Copernicus (1473-1543): heliocentric model more “natural” at explaining retrograde motion.

Johannes Kepler (1571-1630) Ellipses *much* more accurate than circles with epicycles.

Newton: objects move in straight lines (“inertia”) unless acted upon by external force.
Newton proved mathematically that if the gravitational force decreases with the square of the distance (“inverse-square law”) then planetary orbits would be ellipses...

1781: William Herschel discovers a new planet, Uranus.

By 1820s orbit of Uranus deviated from predictions. 1845 Urbain Le Verrier and John Couch Adams predict a new planet... Neptune (“discovered” 1846).

1859: Le Verrier announces discrepancies in orbit of Mercury (“perihelion shift”)...

1905: Einstein develops his *theory of special relativity*, only for constant, linear motion: no change of speed or direction (no acceleration), no gravity.

Special relativity: you cannot do an experiment to determine absolute motion.

General relativity: you cannot do an experiment to distinguish between gravity and acceleration (as in elevator thought-experiment). This is Einstein’s “Equivalence principle” (1907).

Equivalence principle + lots of math = general relativity (Einstein, 1916)

Basic idea: gravity caused by “curved spacetime”

Curved spacetime

Observers who are accelerating will experience “curved” coordinate frames but are still traveling in a “straight line”

You may have already experienced “geodesics” = “shortest path on a curved surface”

Einstein’s general relativity: Gravity occurs because mass “bends” spacetime.

Objects travel on “geodesics” = shortest distance on curved space time

Experimental consequences

- explains perihelion shift of Mercury
- predicts bending of light rays by gravity
- gravitational redshift
- gravity waves

General relativity predicts Sun's gravity will bend path of starlight. Tested in 1919 during total eclipse.

Another prediction: light leaving a planet's gravity will be "redshifted." Tested in 1969 by Pound and Rebka

One more prediction of general relativity: gravity waves. Indirectly detected in binary pulsars (Nobel Prize, Hulse and Taylor, 1993)

Summary of general relativity

General relativity goes beyond special relativity to include acceleration and gravity

General relativity: you cannot do an experiment to distinguish between gravity and acceleration.

General relativity includes Newton's theory of gravity for small masses and velocities

General relativity also explains the perihelion shift of Mercury.

General relativity predicts

- bending of light rays by gravity
- gravitational redshift
- gravity waves
- black holes (not unique to GR)

Evidence for supermassive black hole at center of our galaxy:

<http://www.youtube.com/watch?v=EvuV3GdVaY4>