Relativity

The *History* of Relativity

- Newton's Theory of Gravity – 1687 
- Einstein's Special Theory of Relativity – 1905 … Motion is Relative, c is Constant 
- General Theory of Relativity – 1916
- Comparison of Newtonian vs. Einsteinian
  - Newton thought Gravity was a force across empty space
  - Einstein thought Gravity was equivalent to curved space & space was not empty
- Speed of light: c = 300,000,000 m/sec - speed of all matter and energy - *the speed limit of the universe*
- Maxwell showed that all Electromagnetic Waves to travel at 300,000,000 m/sec 
- Speed of Gravity waves: Newton thought infinite, Einstein thought c
- Equivalence Principle
  - All masses accelerate the same in a gravitational field
    - two different masses - Galileo
    - guinea and feather
    - hammer and feather - David Scott, Apollo 15, 1971
    - dollar bill on top of book
  - Two explanations of equivalence:
    - Newton - gravitational force is proportional to masses so lighter mass is pulled less and therefore two different masses balance to same acceleration - but why?
    - Einstein - curved spacetime
    - Einstein called his "happiest thought": that for an observer falling freely from a roof of a house there exists no gravitational field. If the observer drops a mass it remains at rest relative to the observer. (Let go of a penny on "Free Fall" drop at Great Adventure.) 
    - Therefore, geometry of spacetime equally explains gravity as force explanation.
  - GRAVITY – MOTION - CURVATURE OF SPACE
    - Free Fall on earth at 9.8 m/sec^2 feels like no gravity, weightless
    - Acceleration in outer space at 9.8 m/sec^2 feels like gravity, weight

The *Tests* of Relativity

- ## Mercury's Perihelion Precession
  Newton is off by 43 arcseconds - Einstein corrects Newton by 43 arcseconds

- ## Starlight Deflection
  1919 – Eddington watches solar eclipse in South America and West Africa to see a star appear when it is known to be behind the Sun – showing amount Einstein predicted of curvature of space

- ## Gravitational Redshift - Gravity Probe A
  1960 - a redshift was detected as Einstein predicted. It was a frequency shift of light moving away from earth in an elevator shaft presumed to be due to the light being pulled by gravitational waves. In 1964 Gravity Probe A, a maser clock was flown 10,000 km above earth in a rocket and ran a little faster in lower gravitational field. Like the redshift of light, the time was affected.

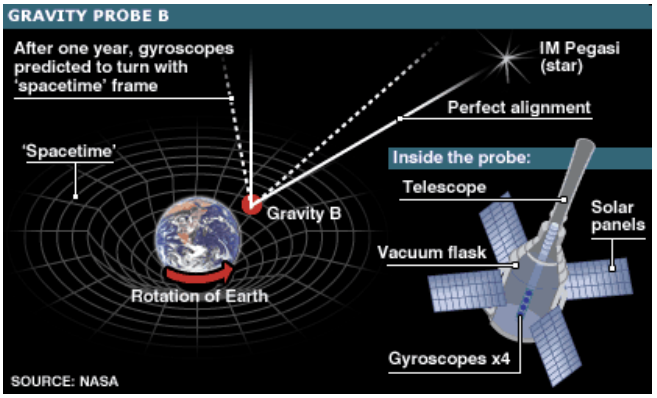
- ## Shapiro Time-Delay
  1964 - radio telescopes took a little longer than expected as if going along curved paths in space - to within 0.5% of Einstein's predictions.

- ## Frame Dragging - Gravity Probe B
  2004 - The best spherical gyros ever made to measure: 1) curvature of space from earth and 2) frame dragging of earth.

  What is *frame dragging*? 1918 - Lense and Thirring predicted that a rotating mass carries a gravitomagnetic current (like an electric current) that disturbs space.

  - The Gravity Probe B Gyroscope Experiment (most conclusive proof of Einstein's theory)

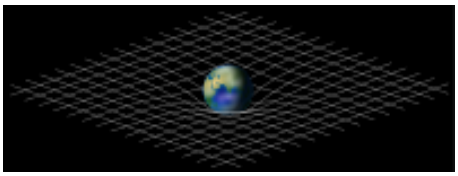
    1. make 4 1.5 inch spherical quartz gyroscopes polished to within a few atomic layers of perfectly smooth - most perfect object ever made (if gyro sphere was scaled to size of earth, highest mountain would be 3m high) - spin it - float it in suspension in a vacuum - least solar, gravitational, pressure, electrical, magnetic, heat, atmospheric interference
    2. put 4 gyros and a telescope and launch in a satellite and point telescope at a distant star as guide - for a full year!
    3. Schiff calculated a prediction of gyros tilting 6.6 arcseconds from curvature of space and 0.041 arcseconds due to frame dragging (this angle would be Lincoln's eye on a penny on the Statue of Liberty as seen from Paris).


GRAVITY PROBE B
After one year, gyroscopes predicted to turn with 'spacetime' frame
IM Pegasi (star)
Perfect alignment
'Spacetime'
Gravity B
Rotation of Earth
Inside the probe:
Telescope
Solar panels
Vacuum flask
Gyroscopes x4
SOURCE: NASA

The *Basics* of Relativity

- Relativity versus Quantum Physics
  - Relativity: high energy - fast (near the speed of light) and/or large masses (sun, stars)
  - Quantum Physics: very small (atomic size)

- Main Ideas
  - Energy and Matter are equivalent ... $e = mc^2$
  - Time and Space are not distinct ... Spacetime is a 4th-dimensional entity that is perceived differently according to the relative motion of the observer.
    - If Observer is moving relative to that which is being observed, *Time is dilated / Length is contracted* (Twin Paradox: one leaves in a rocket ship and returns to find other has aged more.)
    - If Observer is at rest or moving at constant velocity (inertial observers) space-time geometry appears "flat" and obeys the laws of Euclidean geometry.
    - If Observer is accelerating spacetime geometry appears curved (bent or warped). Euclidean rules will not apply.
  - Observer cannot distinguish between a gravitational field and uniform acceleration. (An observer in a room cannot tell if the room is on the surface of the earth or in a spaceship accelerating through deep space with a constant acceleration of 9.8 m/s^2.)
    - Gravity warps spacetime
    - Objects with mass warp spacetime
    - Light always travels along straight lines in spacetime called geodesics. It appears to bend as it follows these geodesic contours of curved spacetime.



- Space is not empty
  - filled with structure
  - structure is "spacetime"
  - it is 4 dimensional
  - it is curved - Curvature of Space explains Gravity and orbits of planets
  - it is twisted - Frame Dragging of rotation of planets explains Twisting of space
  - geometrical properties of space are not independent - *they are determined by matter*
  - *Demo* - oblate spheroid on tilted surface

A *Philosophy* of Relativity

"Reasonable men adapt to the world around them;

unreasonable men make the world adapt to them. ...

The world is changed by unreasonable men."

- Edwin Louis Cole

"I once was lost, but now I'm found"

- Amazing Grace, lyrics by John Newton (1725-1807) Stanza 6 anon

25

There was something undefined and complete,
coming into existence before Heaven and Earth.
How still it was and formless, standing alone, and undergoing no change, reaching everywhere
and in no danger (of being exhausted)!
It may be regarded as the Mother of all things.

I do not know its name,

and I give it the designation of the
Tao (the Way or Course).
Making an effort (further) to give it a name I call it
The Great.

Great, it passes on (in constant flow).
Passing on, it becomes remote.
Having become remote, it returns.
Therefore the Tao is great; Heaven is great; Earth is great;
and the (sage) king is also great.
In the universe there are four that are great,
and the (sage) king is one of them.

Man takes his law from the Earth; the Earth takes its law from
Heaven; Heaven takes its law from the Tao.
The law of the Tao is its being what it is.

- Tao Te Ching, Verse 25 (Tzu, 2012/circa 500 BC)

26

Gravity is the root of lightness; stillness, the ruler of movement.
Therefore a wise prince, marching the whole day, does not go far
from his baggage wagons. Although he may have brilliant prospects
to look at,
he quietly remains (in his proper place),
indifferent to them.
How should the lord of a myriad chariots carry himself lightly before
the kingdom?
If he do act lightly, he has lost his root (of gravity);
if he proceed to active movement, he will lose his throne.

- Tao Te Ching, Verse 26 (Tzu, 2012/circa 500 BC)

References

Tzu, L. (2012/circa 500 BC). *Tao te ching*. Savannah, GA: Green King Press.