

HUBBLE DEEP FIELD (NASA)

**DID EINSTEIN HAVE THE
LAST WORD ON GRAVITY?**

Outline

- Newton
- Special Relativity
- General Relativity
- General Relativity's Successes
- General Relativity's Problems (kind of)
- New Theories
 - Adding Extra (small) Dimensions
 - Adding Length Scales
 - Quantum Gravity
 - Adding Extra (large) Dimensions

NEWTON...

- Mass is the source of Gravity
- Gravity is mediated over distances by an inverse square law ($1/r^2$).

Newton gave us these two important points.

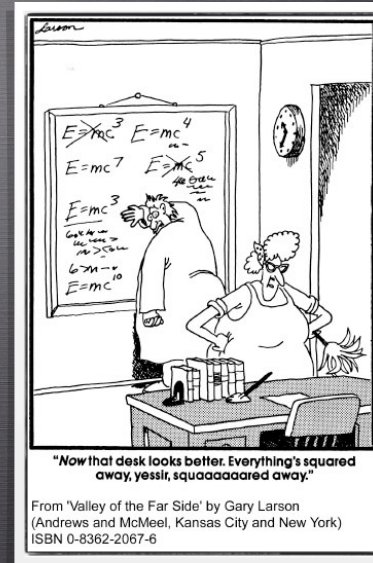
He was never happy with the fact that he couldn't describe fully "action at a distance"

SPECIAL RELATIVITY

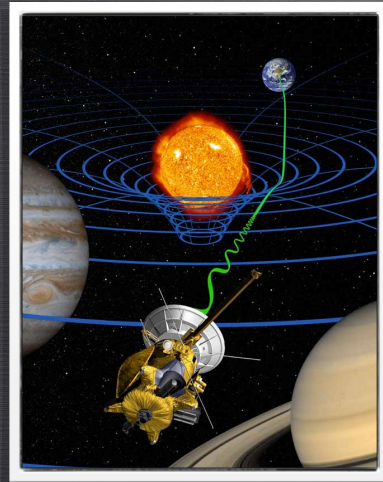
THE SPEED OF LIGHT IS A
SPEED LIMIT AND A
CONSTANT

ALL INERTIAL FRAMES ARE
SUBJECT TO THE SAME LAWS
OF PHYSICS (INCLUDING
THE SPEED OF LIGHT)

$$E=MC^2$$



The inertial frame part is important.



ARTISTS CONCEPT OF CASSINI PROBE TESTING GR (NASA)

GR

EQUIVALENCY PRINCIPLE

ENERGY-MOMENTUM
TENSOR VS. FOUR-CURRENT

GR CAN BE LOOKED AT AS
AN ANALOGY TO EM:
ENERGY \leftrightarrow |CHARGE|

SPACETIME TELLS MATTER
HOW TO MOVE; MATTER
TELLS SPACETIME HOW TO
CURVE.

Equivalency Principle.

spacetime tells matter how to move; matter tells spacetime how to curve.

$E=MC^2$. links Energy, Momentum, (and hence stress and pressure). hence the source of gravity is a 2 dimensional matrix.

The fact that the EM tensor is second order is the reason the Graviton is commonly cited as being Spin 2. The Photon is Spin 1 because the 4-current is a first order tensor.

GR'S SUCCESSES

- The advancing perihelion of Mercury
- Deflection of light by the Sun
- Gravitational Lensing
- Gravitational Time Dilation

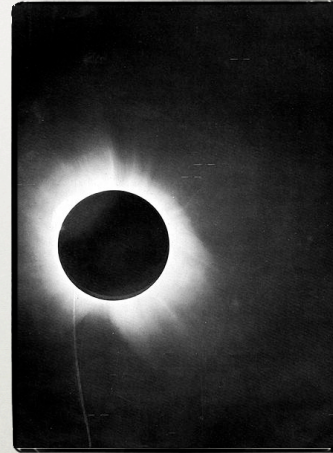


Photo of the eclipse taken by Eddington in 1919

The most famous of Einstein's tests of GR was when he predicted that a star, when passing behind the Sun, would shift in position. His prediction proved accurate during a solar eclipse


in 1919, Sir Arthur Eddington, along with Frank Dyson measured the shift of a star during the solar eclipse as it passed behind the sun. When he announced his results, the news was all over the papers at the time

When asked by his assistant what he would think if his theory was disproved by the Eddington observations, Einstein quipped: "Then I would feel sorry for the dear Lord. The theory is correct anyway."

**PROBLEMS
WITH GR**
(KIND OF...)

**BLACK HOLES & COSMIC
STRINGS**

**QUANTUM THEORIES OF
GRAVITY ARE
NONRENORMALIZABLE AT THE
PLANK SCALE.**



[HTTP://WWW.TEMPOLIMIT-LICHTGESCHWINDIGKEIT.DE/GALERIE/GALERIE.HTML](http://www.tempolimit-lichtgeschwindigkeit.de/galerie/galerie.html)

GR has passed every “unambiguous” observational and experimental test.

Spacetime Singularities are where Spacetime curvature is no longer smooth. It isn’t really clear if these are a non-physical artifact of GR (in which case, the theory needs work), or if Singularities actually occur in nature.

Quantum Gravity: Is there a quantum version of GR? The big reason to look at this are because of the great successes of quantizing the other three forces. A quantized theory of gravity is likely to play a role in the very high energy, and very small dimensioned world of Black Holes and the beginning of the Universe.

the Velocity Curves of Galaxies (first seen by Fritz Zwicky in 1933), gave the possibility that gravity at large scales might need modification.

LETS ADD SOME EXTRA (SMALL) DIMENSIONS

- Kaluza–Klein theory (1921)
 - Unifies GR and EM in 5 Dimensional Spacetime

Kaluza–Klein theory (1921): unifies GR and EM in a five dimensional spacetime.

The 4th spatial dimension is compactified (1926), and wrapped up in a circle.

Was the first theory that looked at using extra dimensions to try and unify forces. However, its not strictly a quantum theory.

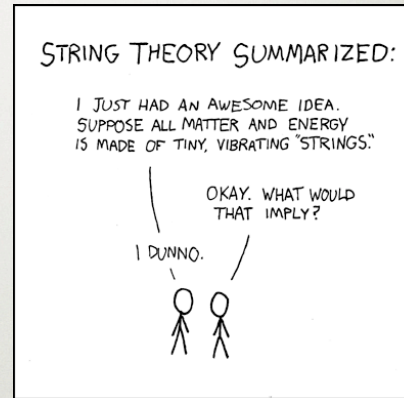
You can still get standing waves in the extra compactified dimension(s).

If an extra dimension is of radius R , the energy of such a standing wave would be $E = nhc / R$ with n an integer, h being Planck's constant and c the speed of light. This set of possible energy values is often called the Kaluza–Klein tower.

QUANTUM THEORIES OF GRAVITY

(AND UNIFICATION THEORIES)

- Loop Quantum Gravity (1988)
- String Theory
- Supergravity (1976)
- M-Theory (1995)



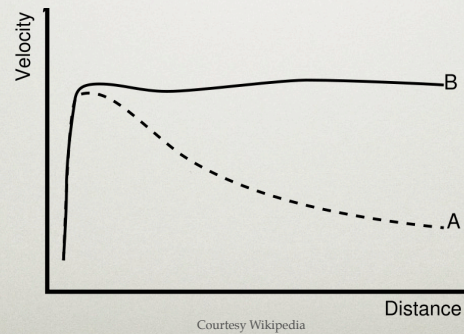
Loop Quantum Gravity: Loop quantum gravity suggests that space can be viewed as an extremely fine fabric or network "weaved" of finite quantised loops of excited gravitational fields called spin networks.

Supergravity: Unifies supersymmetry and string theory with a whole bunch of assumptions. The supersymmetric particle of the graviton with spin 2 is the gravitino, with spin 3/2.

String Theory (Witten): fundamental particles are all excitations of 1 dimensional strings.

OR A LENGTH SCALE TO GR

- MOND theory (1983)
 - Lost favor to Dark Matter

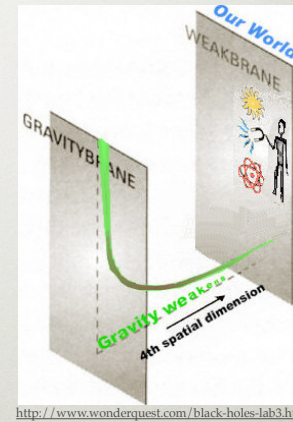


Then there is MOND (Modified Newtonian Dynamics.)

Modify gravity to include a length scale.

WHAT ABOUT ADDING SOME EXTRA (LARGE) DIMENSIONS

- ADD Model (1998)
- Randal-Sundrum Theory (1999)
- We are on a 3+1 dimension brane in a higher dimensional universe



Why is gravity weaker?

ADD Model: (Nima Arkani-Hamed, Savas Dimopoulos, and Gia Dvali)

If there are extra dimensions of size d , then for $r \ll d$, gravity is $1/r^{(2+d)}$, and for $r \gg d$, gravity is $1/r^2$. because some of the force of gravity leaks into the other dimensions.

Randal-Sundrum Theory:

The fifth dimension is warped so that at one end the natural energy scale is the plank energy, and at one end the natural energy is 1TeV.

These are two 4-branes in a 5 dimensional spacetime. One is called the plankbrane (or gravitybrane) (plank scale energy), and one is called the weakbrane (or Tevbrane) (TeV scale energy). Essentially the plankbrane is where the probability function of gravity is largest, while on the weakbrane, its probability function is much lower. We “live” on the Tevbrane (along with all the Standard model forces). For this theory, the energy level at which we might be able to detect these extra dimmensions is much lower than the plank scale, (it is actually around 1TeV).