General Relativity:

Einstein's Theory of Gravitation

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The Motivations of General Relativity

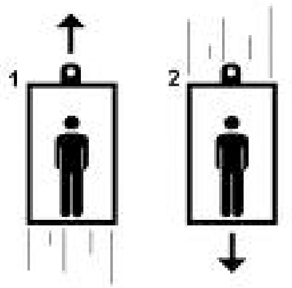
- General Relativity, or GR, was created in order to better understand gravity
- It has helped us to answer why gravity exists
- General Relativity has many predictions most of which have been verified by experiment with amazing accuracy

The Motivations of GR

- The special theory of relativity encompasses inertial frames of reference moving at uniform relative velocities
- Einstein asked whether or not systems moving in nonuniform motion with respect to one another could be relative and came up with the idea of general relativity

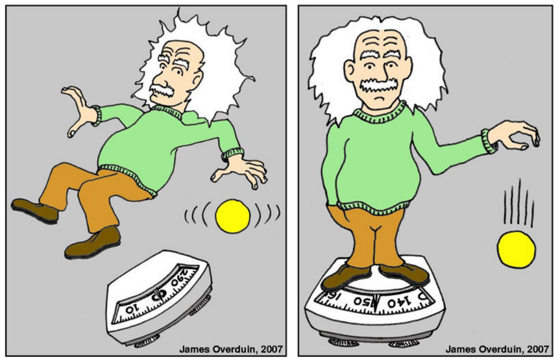
The Equivalence Principle

- The equivalence principle is the fundamental underpinning of general relativity, it says that:
- "There is no experiment that can be done in a small confined space that can detect the difference between a uniform gravitational field and an equivalent uniform acceleration."



The History of GR

- Developed between 1907 and 1915
- The beginnings of GR germinate in 1907 with Einstein's thought experiment concerning a free-falling observer that he called the happiest thought of his life: *"For an observer falling freely from the roof of a house, the gravitational field does not exist"*



The History of GR

- 1907- published first paper applying SR to accelerating reference frames that also predicted gravitational time dilation
- 1911- published paper predicting gravitational lensing
- 1912- Einstein was focused on formulating a theory of spacetime that was purely geometrical

The History of GR

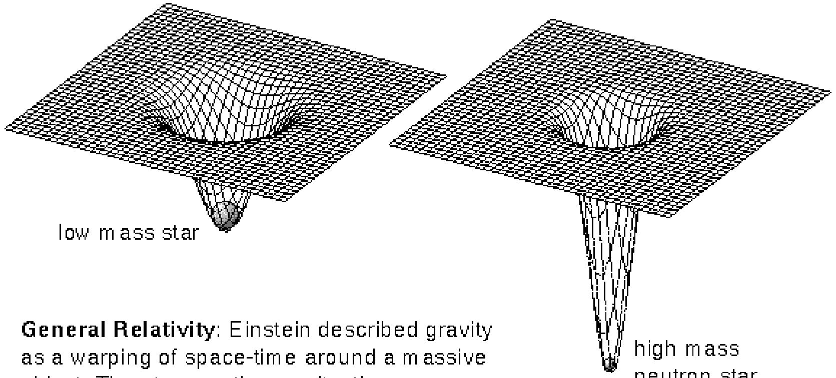
- By 1915 Einstein had developed what are known as the Einstein Field Equations

- General Theory of Relativity published in Annalen der Physik in 1916

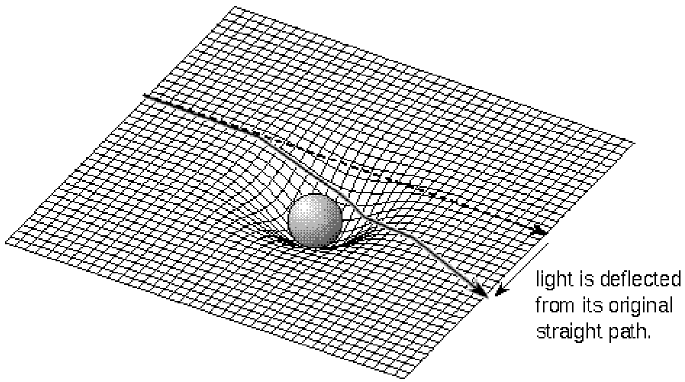
The Characteristics of GR

- GR is a theory of gravitation that supersedes Newton’s Law of Universal Gravitation using the warping of spacetime by mass to explain gravitational attraction instead of the idea of “forces”
- Essentially, massive bodies warp and curve their local spacetime

An Example of Curved Spacetime



General Relativity: Einstein described gravity as a warping of space-time around a massive object. The stronger the gravity, the more space-time is warped.



General Relativity: Light travels along the curved space taking the shortest path between two points. Therefore, light is deflected toward a massive object! The stronger the local gravity is, the greater the light path is bent.

Some Predictions of GR

- Geodetic Deviation
- Frame Dragging
- Gravitational Lensing
- Black Holes
- Gravitational Redshift
- Gravity Waves

Geodetic Deviation

- Arises from the transportation of angular momentum through gravitational field when EFE are applied to a massive body
- Massive bodies like Earth warp spacetime and a spinning object (i.e. gyroscope) orbiting the larger body will exhibit a precession of its axis of rotation
- Gravity Probe B

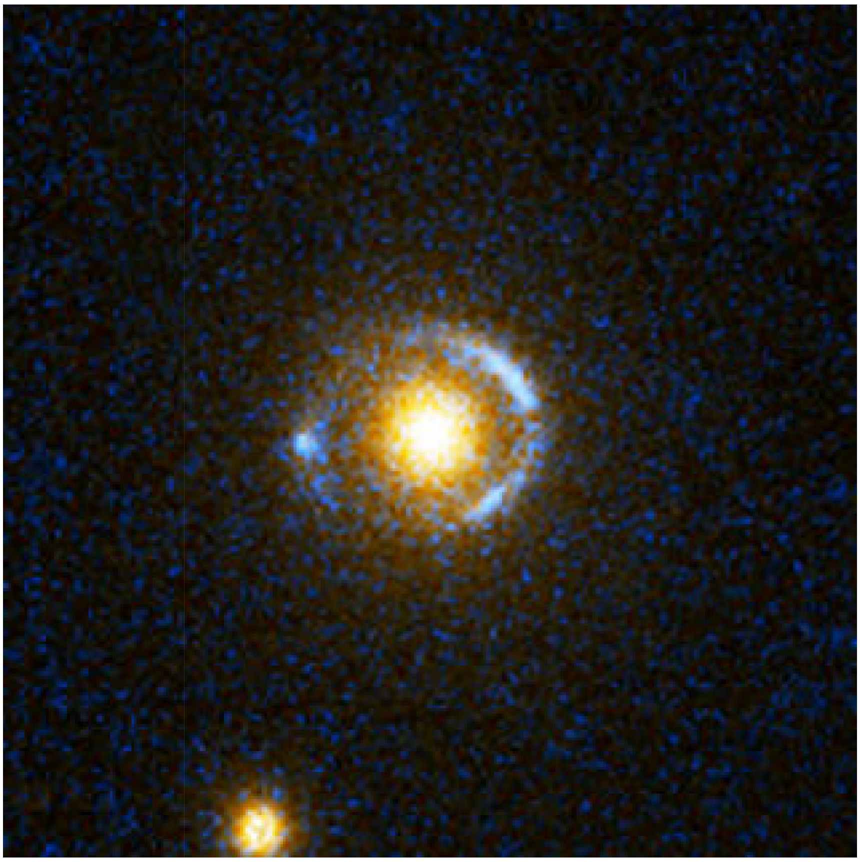
Frame Dragging

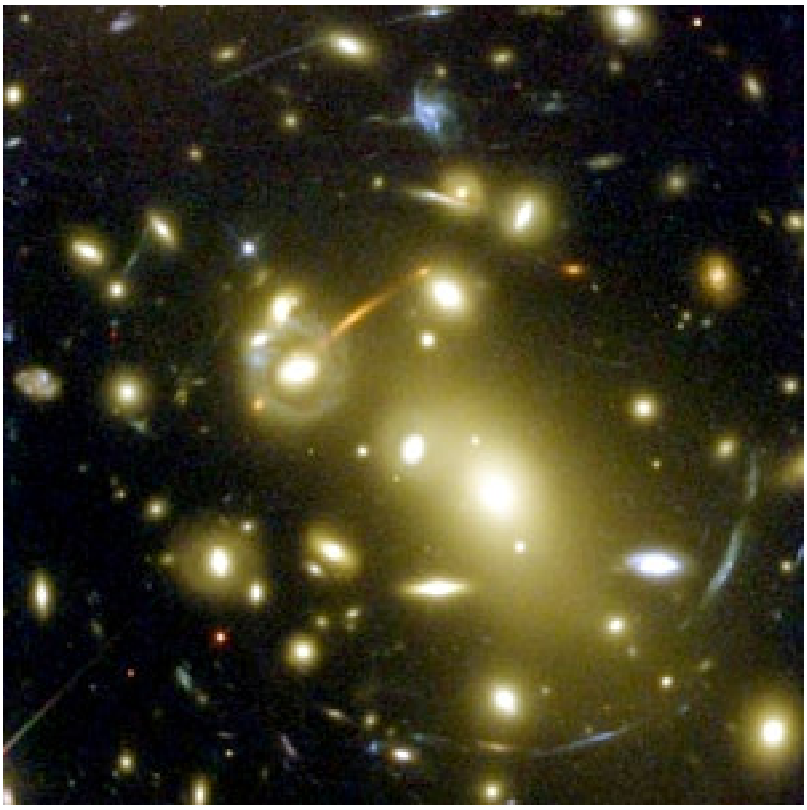
- Derived by Hans Thirring and Josef Lense (AKA Lense-Thirring Effect)
- Rotating massive bodies pull spacetime around with them
- Frame Dragging Effect

Gravitational Lensing Effect

- The Gravitational Lensing effect occurs when light reaching an observer has passed by a very massive body which is heavily distorting space. The light can be seen, (of course), to bend around the body.


Gravitational Lens G2237+0305





Black Holes

- Black Holes are the most profound prediction of general relativity
- A black hole is a large body of matter that is so dense that nothing can escape its gravitational attraction, at a given distance, known as the Schwarzschild radius

Gravitational Redshift

- Gravitational redshift occurs when light leaving a massive body redshifts in order to conserve energy
- Light can also blueshift if falling into a gravity well
- The appropriate equation for the red shift is

$$hf = hf' + hf\frac{gH}{c^2}$$

Gravitational Waves

- Fluctuation of spacetime curvature that is propagated as a wave
- Radiates away from accelerating bodies
- Carries energy away from source
- Predicts that two massive bodies rotating about their center of mass will loose energy in the form of gravity waves and the orbit will decay

Experimental Verifications of GR

- Gravity Probe B
- Black Holes
- Eddington’s 1919 expedition to Africa
- Pound and Rebka (Gravitational Redshift)

Enter Gravity Probe B

- Collaborative experiment between NASA and Stanford
- Utilized putting world's most perfect gyroscopes in polar orbit around earth, launched in 2004
- Gravity Probe B was designed to detect the Geodetic Deviation and Frame dragging effects due to the spacetime warping of the Earth

Geodetic Deviation Measurements

- Confirmed by GP-B with total of 1% experimental uncertainty
- Hoped that by 2010 analysis will yield 0.01% uncertainty

Frame Dragging Measurements

- Current data analysis yields 15% statistical uncertainty
- Hoped to be down to 1% by 2010

Black Holes

- Do they exist? FOR SURE!
- Black Holes come in two different sizes: Stellar (5 to 20 solar masses) and supermassive (millions or billions of times the mass of the sun)
- Black Holes are detected by either their gravitational influence on nearby bodies or through electromagnetic radiation

Gravitational Redshift

- Measured accurate to within 0.02% of the predicted value by Pound and Rebka in 1960 in the tower of Harvard University

Further Implications of GR

- Cosmology-the ultimate fate of the universe

- The Hawking Effect-the first combination of the quantum theory with general relativity

Conclusion

- What have we learned from general relativity?
- What can we predict using GR?
- GR is one of the most accurate physical theories to date

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Sources

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