Understanding and Testing Relativity

From Einstein's formulations to the tests of today

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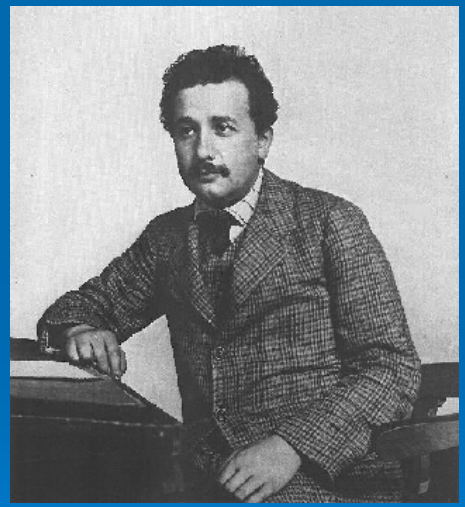

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Introduction

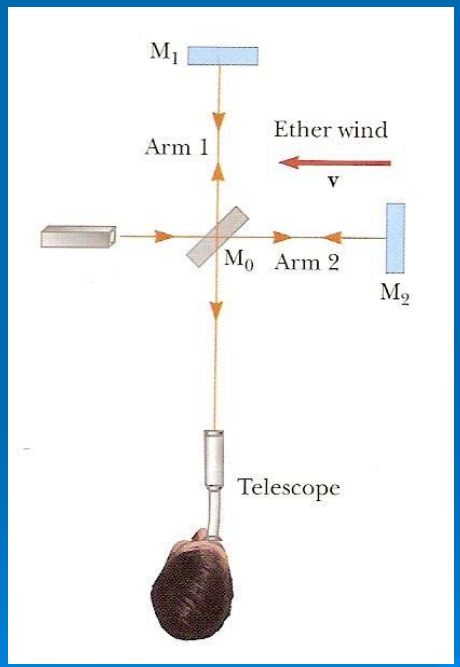
- Defining special and general relativity
- Tests for special relativity
- Current tests for general relativity
- Implications of special and general relativity – a new perspective of the universe

How special relativity began…

- Albert Einstein, 1905
- All inertial reference frames equivalent
- Michelson-Morley experiment
- Speed of light constant in all reference frames
- James Maxwell

Michelson-Morley experiment

Principles of Physics - Serway



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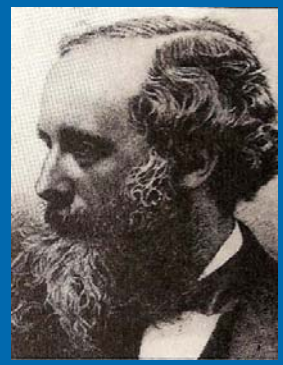
- Disproved the long standing belief in ether
- Ether – a holdover from Newtonian “absolute space” and preferred reference frames
- Tried to observe out-of-phase light created by earth’s motion through the ether
- Scientist tried to save the ether theory – H. Lorentz

James Maxwell

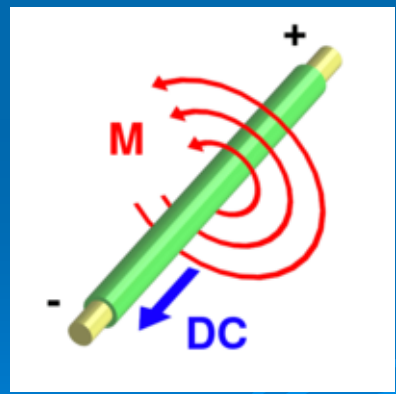
- Maxwell unified the previously mutually excusive forces of electricity and magnetism
- In studying electromagnetism – found light to propagate at same velocity as electromagnetic waves
- Maxwell remained tied to the ether theory



Principles of Physics - Serway

$$
\begin{aligned}
&1.\quad \nabla \times \boldsymbol{E} = -\dot{\boldsymbol{B}} \\
&2.\quad \nabla \times \boldsymbol{H} = \boldsymbol{J} + \dot{\boldsymbol{D}} \\
&3.\quad \nabla \cdot \boldsymbol{B} = 0 \\
&4.\quad \nabla \cdot \boldsymbol{D} = \rho
\end{aligned}
$$

A Dynamical Theory - Maxwell



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Testing special relativity

- Test whether the velocity of light depends on emitting source
- Testing the consequences – everyday consequences
  - Global Positioning System
  - Satellite ranging
  - Particle accelerators

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Onward to general relativity

- 1916 – an extension of special relativity to include gravitation and space-time
- A uniform gravitational field is equivalent to uniform acceleration
- Time is relative
  - Closer to the speed of light – time seems to slow
  - Within a gravitational field there is a “time dilation” that seems to slow the passage of time
- Einstein’s field equations:
- String Theory

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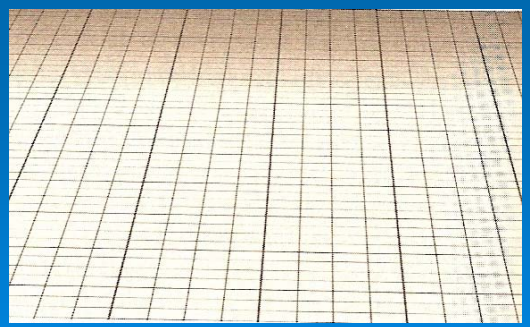
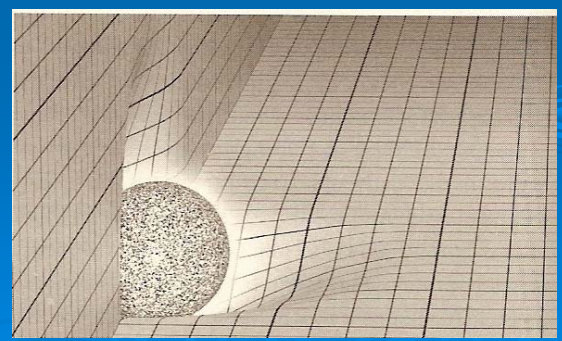
Space-time

- A consequence of general relativity
- Like a fabric that stretches throughout the universe
- Fabric bends and distorts in the presence of massive objects



The Elegant Universe - Greene



The Elegant Universe

Testing general relativity

- Search for gravitational waves predicted by general relativity
- (Movement of) Massive bodies in space create ripples in space-time
- Gravitational waves emitted by accelerating massive objects -

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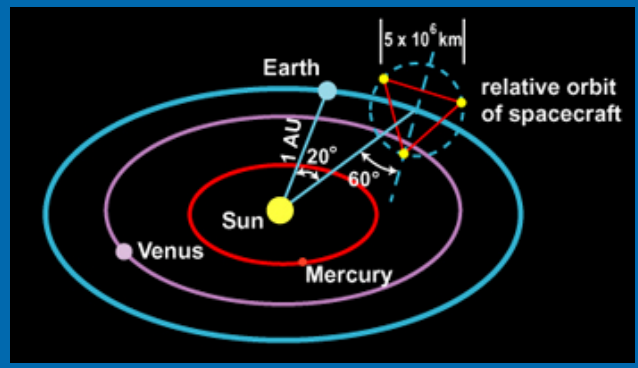
LISA

- Laser Interferometer Space Antenna
- LISA spacecrafts detect waves through light interference patterns
- Gravitational waves originating from binary systems, black holes, and stars
- Operating frequency: ~10^{-4} to 10^{-1} Hertz



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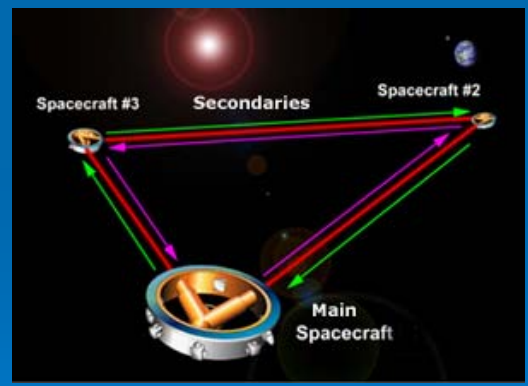

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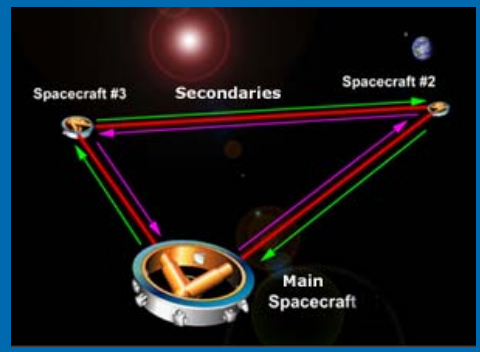
LIGO

- A land based form of LISA
- Laser Interferometer Gravitational-Wave Observatory
- A large scale Michelson-Morley experiment
- Located in several locations i.e.: Hanford, WA and Livingston, LA
- Problems with LIGO
  - Local disturbance cause inferometer to detect “gravitational waves’
  - Limited distance

wwwrel.ph.utexas.edu

How it works…again

- Light is split by beam splitter
- Sent through two arms of equal distance and bounced off a mirror and returned to a “sensor”
- On this journey, the beams can be skewed by gravitational waves
- The inference patterns (out of phase light) created by the recombined light – indicates the light was disturbed



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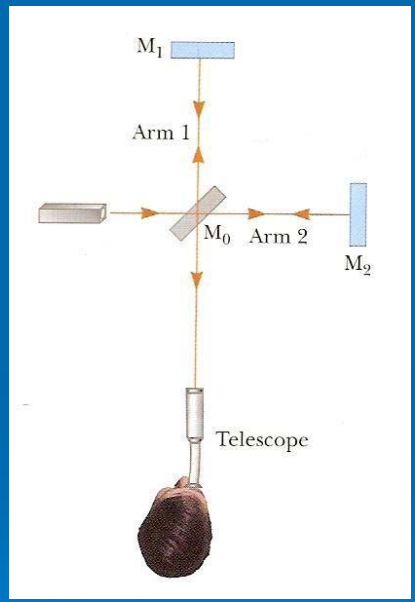

Principles of Physics

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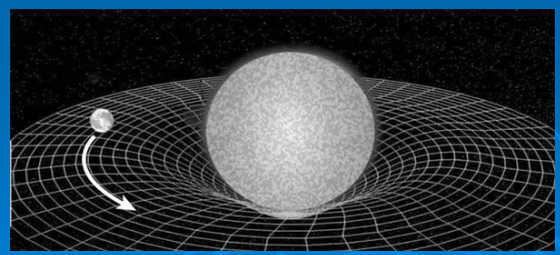
A New Perspective of the Universe

- Newtonian viewpoint – rigid orbits, defined by gravitational attraction
- Newton did not understand HOW gravity worked
- Einstein revolutionized the picture of the universe
- Space-time
- Special relativity governs the technology in our everyday lives
- General relativity continues to be a topic of study

A Briefer History of Time - Hawking



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