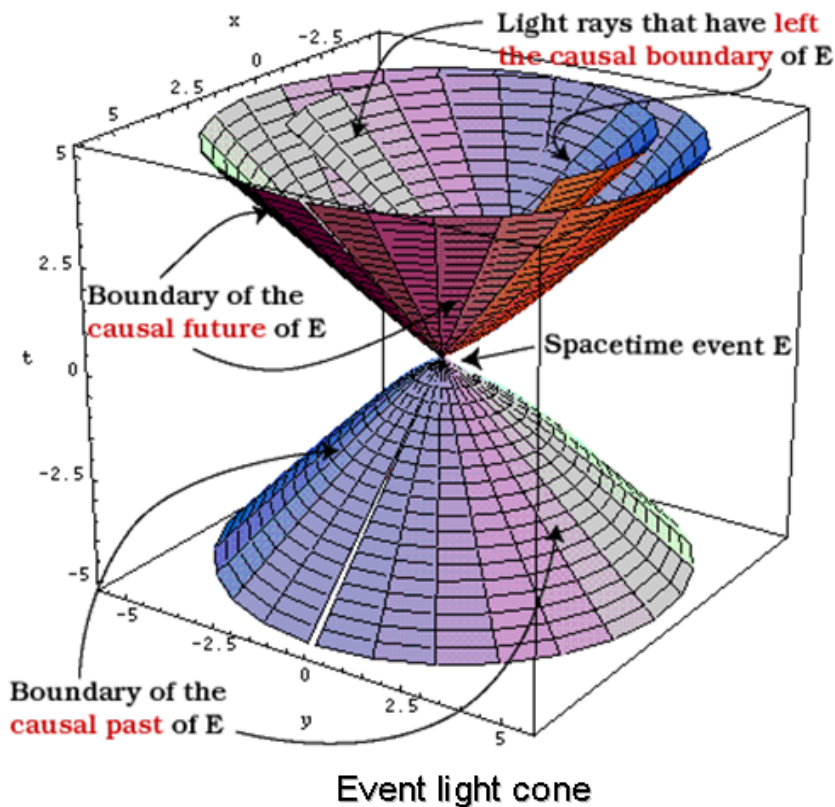


Albert Einstein and the Geometry of Space and time

Reading: Chapter 3 of the "State of the Universe"



Concepts of Space and Time

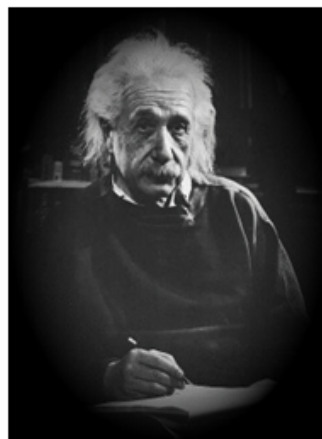


□ Newton has put physics on solid mathematical footing, by developing calculus.

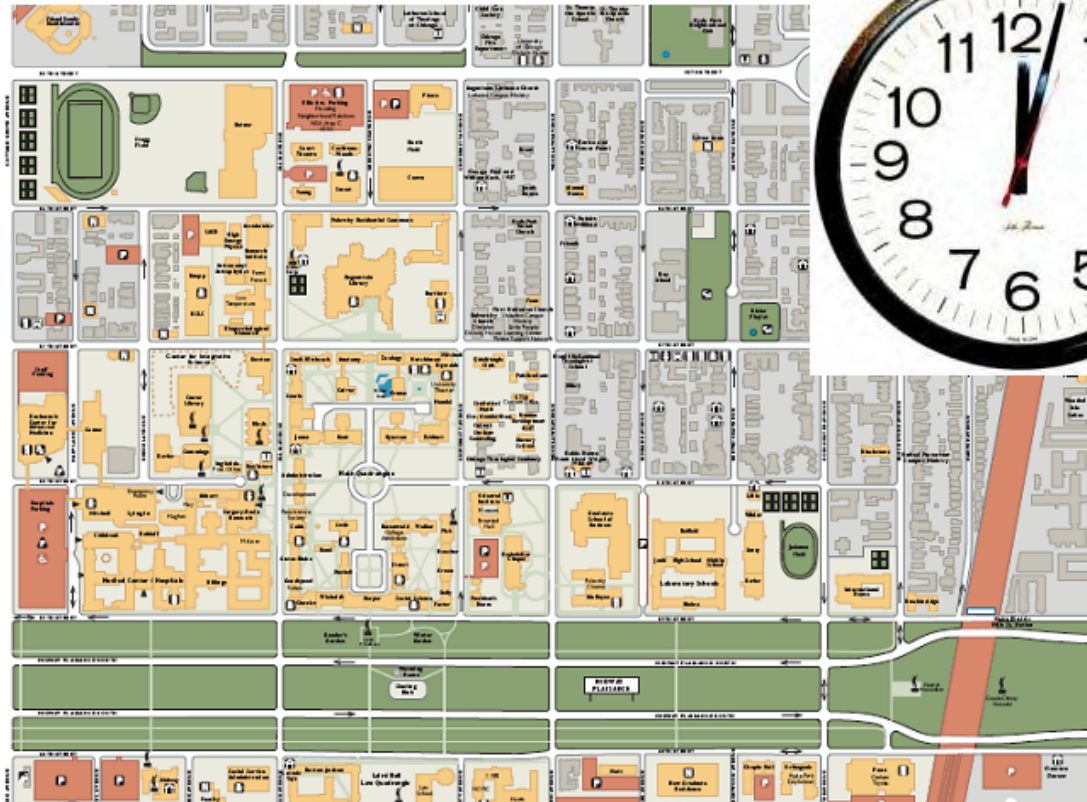
□ Time and space are part of the mathematical equations. They become physical and mathematical concepts, not necessarily related to the human notion of time

□ However, the question turned out to be more complicated. Space and time in the laws describing the physical Universe often behaves counter to human intuition.

□ In physics and cosmology the space and time are integral parts of the inseparable space-time that forms the fabric of the Universe

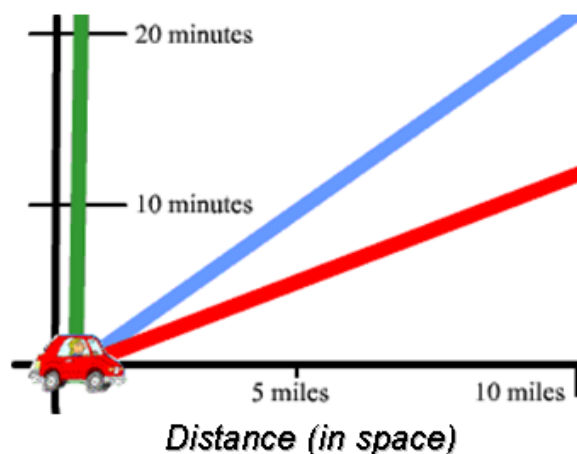


Traditional Concepts of Space and Time

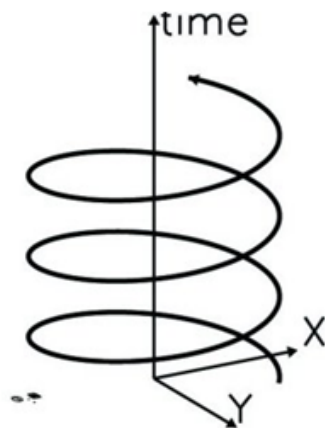


Concepts of Space and Time

Time (starting from some event)



www.theory.caltech.edu/people/patricia/st101.html



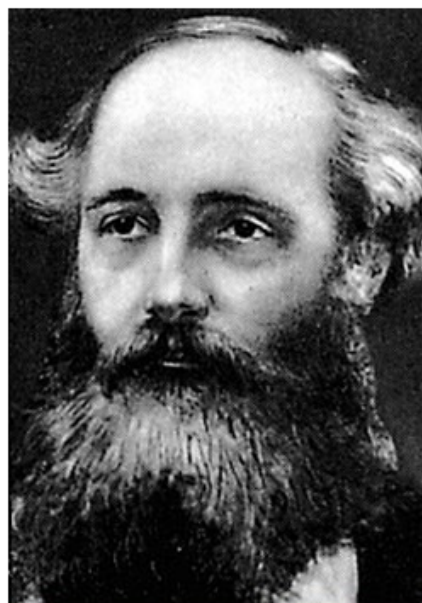
Earth orbit in space-time

Inertial Reference Frames

- Newton's 2nd law of mechanics: $F=ma$, m is the inertial mass. Inertia is an inherent property of physical bodies (hence the need for seatbelts!)
- Unaccelerated motion ($a=0$) is called inertial motion
- Frame of reference in inertial motion is called inertial reference frame. A particle on which no forces act, will move uniformly in an inertial frame
- Spatial distances and time are *relative*, but Newton's laws of motion will be the same (or *invariant*) in all inertial frames (trajectory of a ball on a moving train). This is called the Galilean Principle of Relativity

Q: Examples of inertial frames? Is the Earth inertial reference frame?

Maxwellian theory of Electromagnetism

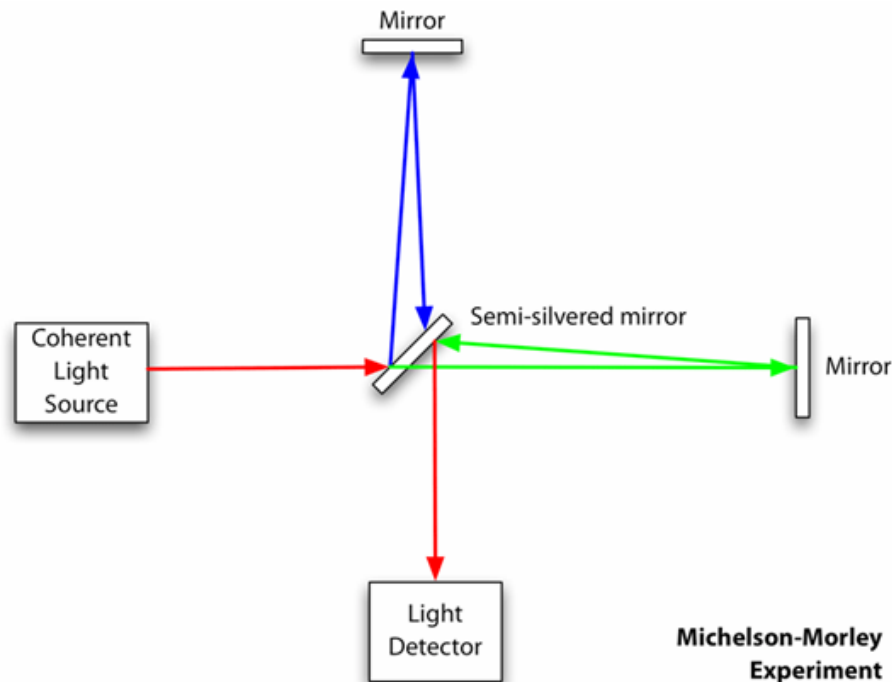
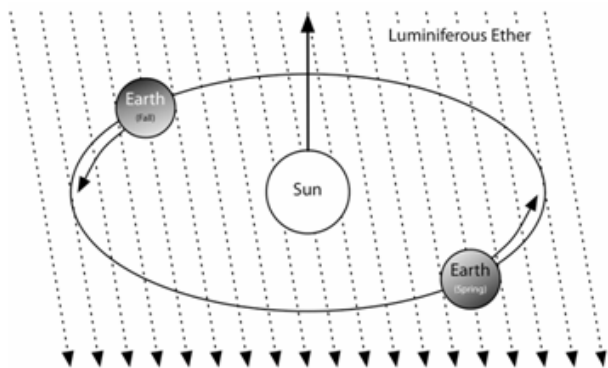


James Clerk Maxwell
(1831-1879)

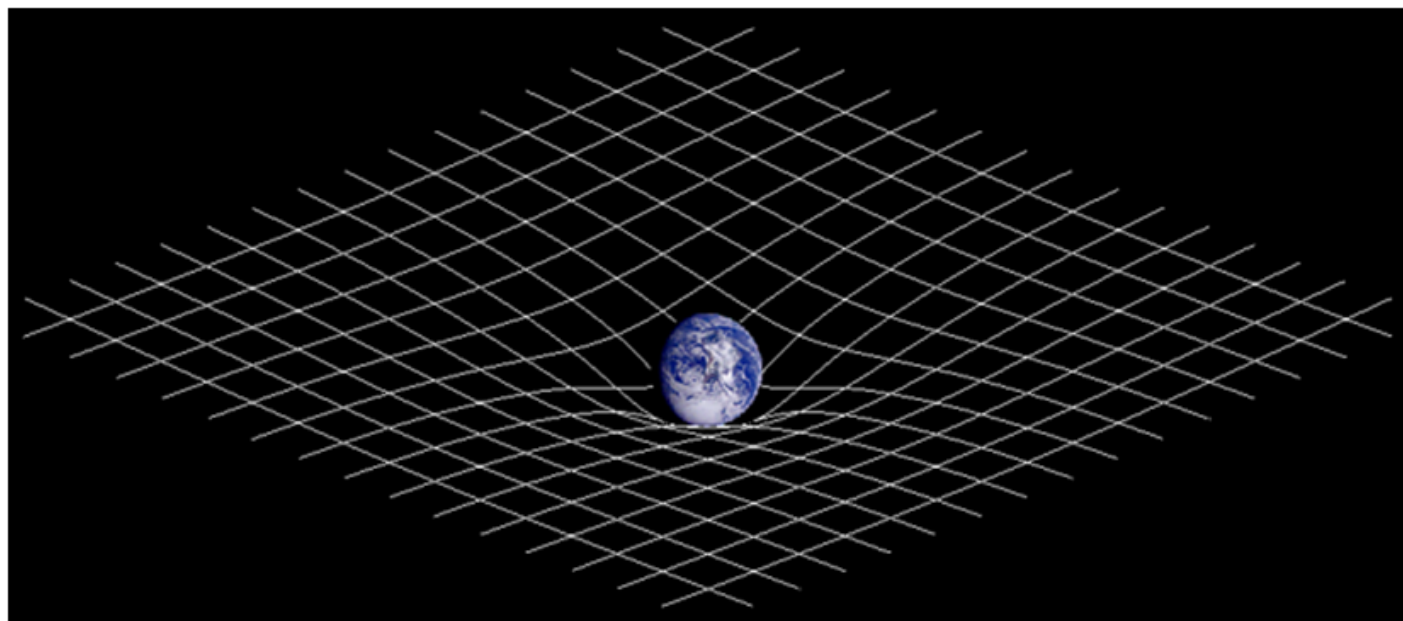
- 1860s. Maxwell developed his theory of electromagnetism that explained electric and magnetic forces as part of the same phenomenon. Prediction of electromagnetic waves propagating with the speed of light. Later identified with the light itself.
- Maxwell equations depend on the speed of light c . If the velocity is relative, is the speed of light relative? If so, Maxwell equations would be different in different inertial reference frames.
- A possible solution: existence of an absolute reference frame defined by the *ether*, in which electromagnetic waves propagate. Maxwell equations would be applicable to the reference frame defined by the ether.

Michelson-Morley experiment

Showed no evidence for ether as motion of the Earth seemed to create no preferred direction and speed of light was measured to be the same independent of direction



Relativity and Gravity



“Spacetime grips mass, telling it how to move, and mass grips spacetime, telling it how to curve” – John Archibald Wheeler.

Special Relativity Theory



Albert Einstein
In 1905

□ 1905 (Einstein's Miracle Year). Albert Einstein published the Special Theory of Relativity

Postulates of the theory:

- All laws of nature are the same (invariant) in all inertial reference frames (this is called the relativity principle)
- The speed of light is constant in all inertial frames (this leads to the Lorentz transformation, which Einstein argued supersedes Galilean transformation)

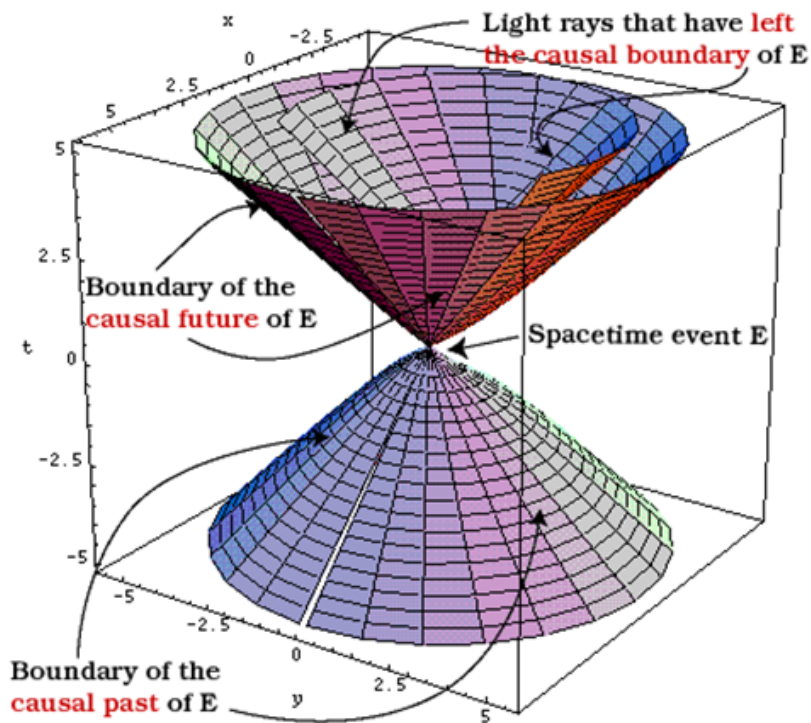
*Simple... but many surprising consequences:
Dilation of time, contraction of length*

Chapter 3 describes some of the interesting implications and paradoxes

Special Relativity Theory

- ❑ Special relativity theory predicts that many things we intuitively think to be invariant (length, interval of time, synchronicity or simultaneity of events) are actually relative (depend on the frame of reference).
- ❑ What is invariant is the space-time interval. The time and space are thus tightly linked and are physically connected in this theory. Einstein used Minkowskian space-time – geometrically flat, four-dimensional space-time to write down equations and transformations of the special relativity.
- ❑ The special theory of relativity has been extensively tested experimentally in many situations (in particular in particle accelerators, and in observations of astrophysical objects in which large velocities are present)

Speed of light and light cone



Event light cone



We see distant galaxies as they once were, not as they are today (HDF movie)