ASTR 1040 Recitation: Relativity

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February 17 & 19, 2014

This Week

- Fiske Planetarium: Thurs Feb 20 (9:30 am)
- Observing Session: Thurs Feb 20 (7:30 pm)

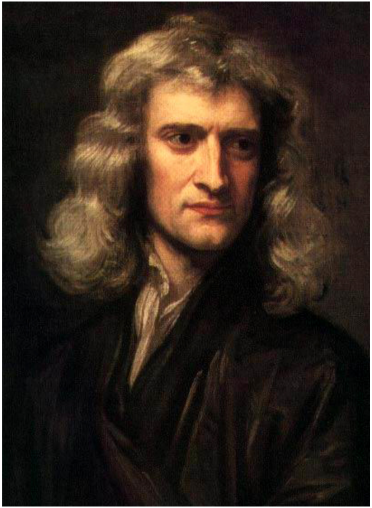
Today's Schedule

- Special Relativity
- General Relativity
- Black Holes

History of Relativity

Newton's Relativity:

- Laws of physics are the same for all inertial frames
- Time is the same for everyone
- Apply a constant force to an object, it will accelerate forever

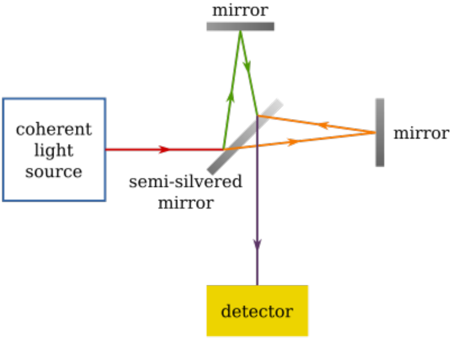


History of Relativity

Maxwell's E & M:

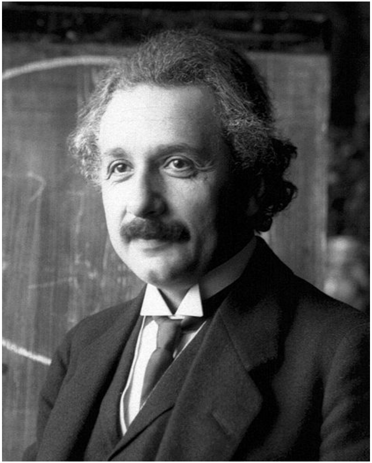
- Laws of physics set speed of light at $\sim 3 \times 10^8$ m/s
- How can all reference frames measure same light going same speed?
- Idea of a universal rest frame $\Rightarrow$ "aether"

Michelson-Morley Experiment: Find the universal rest frame



Einstein's Relativity:

- Laws of physics (including speed of light) are same for all inertial frames
- Measuring things like time, length and mass depends on your reference frame



Special Relativity

As objects travel faster and faster ...

- Their relative time slows down (time dilation)
- The object becomes shorter (length contraction)

Special Relativity

Time Dilation: $t = \gamma \tau_p$

Length Contraction: $L = \frac{L_p}{\gamma}$

Lorentz Gamma Factor: $\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}$

Special Relativity

Rest Frame Coords: t, x, y, z

Moving Frame Coords: t', x', y', z'

- $ct' = \frac{ct - vx/c}{\sqrt{1 - v^2/c^2}}$
- $x' = \frac{x - vt}{\sqrt{1 - v^2/c^2}}$
- $y' = y$
- $z' = z$

Special Relativity

How do velocities add? Is the speed of light held constant?
Two frames moving at velocity v with respect to one another

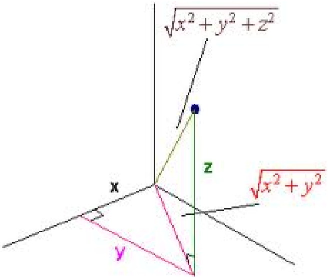
$$u' = \frac{x'}{t'} = \frac{\frac{x-vt}{\sqrt{1-v^2/c^2}}}{\frac{t-vx/c^2}{\sqrt{1-v^2/c^2}}} \qquad \Rightarrow u' = \frac{x-vt}{t-vx/c^2}$$

$$u' = \frac{x-vt}{t-vx/c^2} \quad \Rightarrow \quad u' = \frac{t(x/t-v)}{t(1-vx/(tc^2))} \quad \Rightarrow \boxed{u' = \frac{u-v}{1-vu/c^2}}$$

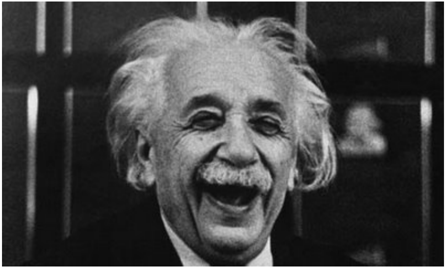
If $u = c$:

$$u' = \frac{c-v}{1-vc/c^2} \qquad \Rightarrow u' = \frac{c-v}{1-v/c} \qquad \Rightarrow u' = \frac{c(c-v)}{c-v} = c$$

Geometry you didn't learn in High School

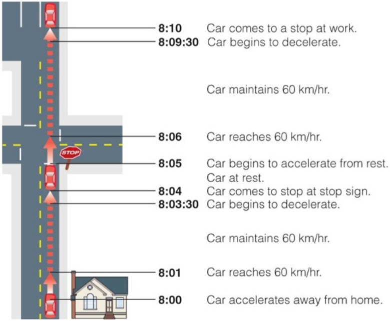


- Constant in any reference frame: $ds^2 = dx^2 + dy^2 + dz^2$

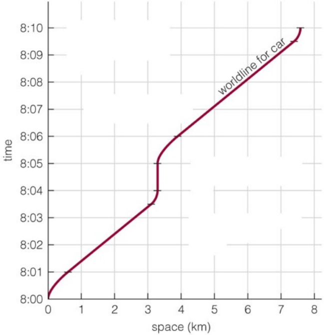


- Constant in any reference frame: $ds^2 = -c^2dt^2 + dx^2 + dy^2 + dz^2$

Thinking of Time as an Extra Dimension



a This diagram shows the events that occur during a 10-minute car trip from home to work on a straight road.



b We make a spacetime diagram for the trip by putting space (in this case, the car's distance from home) on the horizontal axis and time on the vertical axis.

General Relativity

Special Relativity (1905)

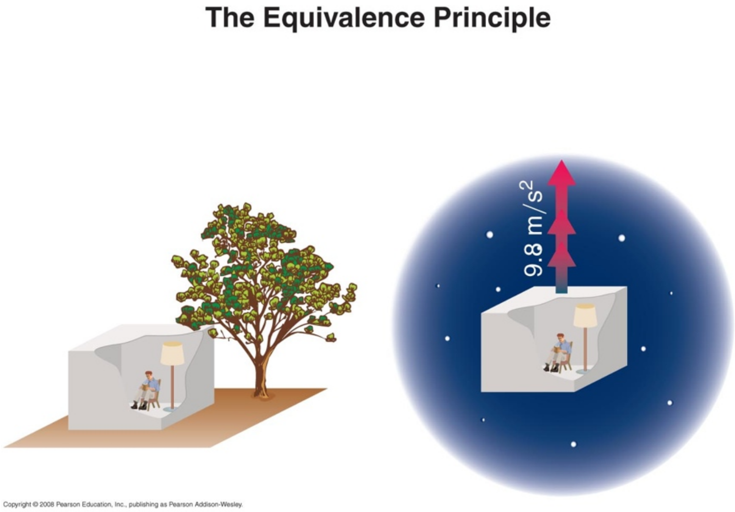
- Laws of physics are same for all inertial reference frames
- Speed of light is constant in all intertial reference frames
- Does not explain how forces work

General Relativity (1915)

- Laws of physics are same for ALL reference frames
- Gravity is caused by massive objects “bending” space-time
- No difference between gravity and an accelerating ref frame

General Relativity

Equivalence Principle: stationary in gravity = accelerating w/o gravity



General Relativity

Equivalence Principle: freefall in gravity = constant velocity w/o gravity

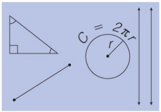
- Constant velocity v, if $u = v$
- $u' = \frac{u-v}{1-vu/c^2}$
- Objects are not moving with respect to you $\Rightarrow$ think astronauts floating in the Space Station (freefall)

General Relativity

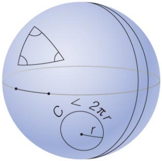
This leads to some strange results:

- Curved space-time
- Black holes

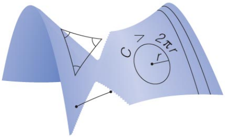
Curvature



a Rules of flat geometry.

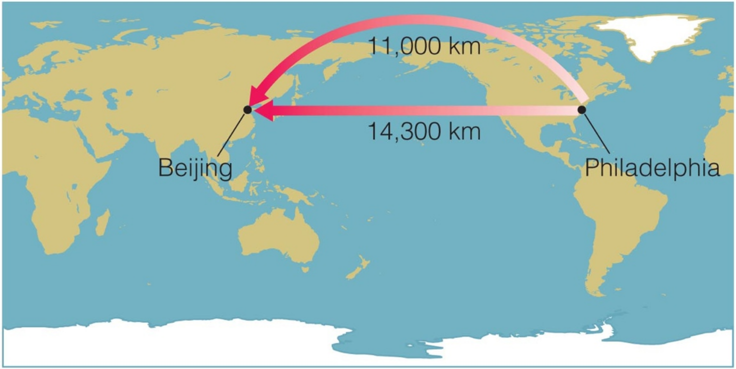


b Rules of spherical geometry.



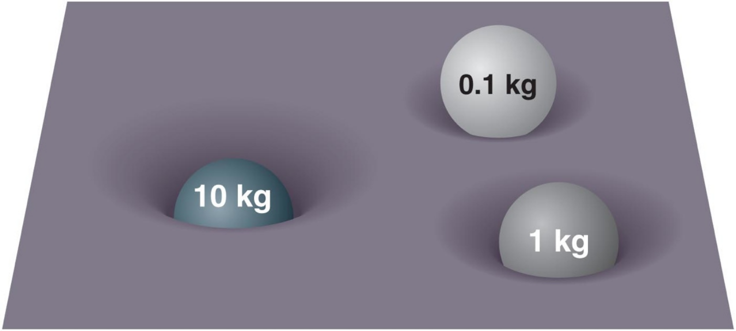
c Rules of saddle-shaped geometry.

Curvature

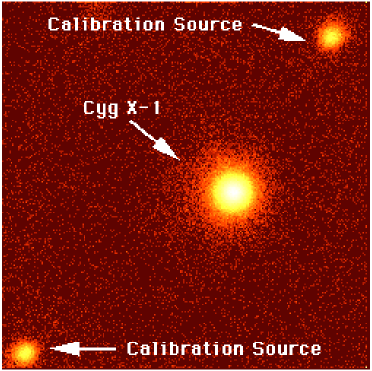


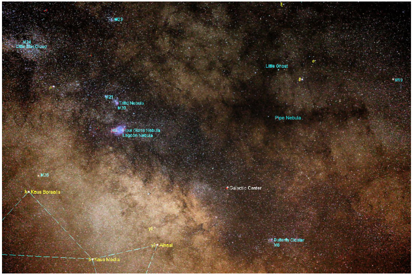
Curvature

Matter tells space how to curve



Black Holes

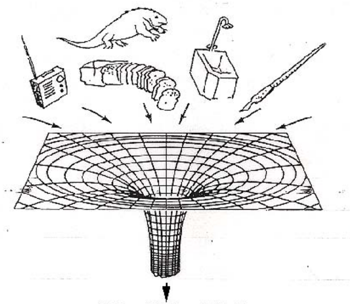

Calibration Source
Cyg X-1
Calibration Source


M23
M24
Little Star Cloud
Little Ghost
M19
M21
Trifid Nebula
M20
Pipe Nebula
M8
Hour Glass Nebula
Lagoon Nebula
M28
Keus Borealis
Galactic Center
Butterfly Cluster
M6
Alnasl
Kaus Media

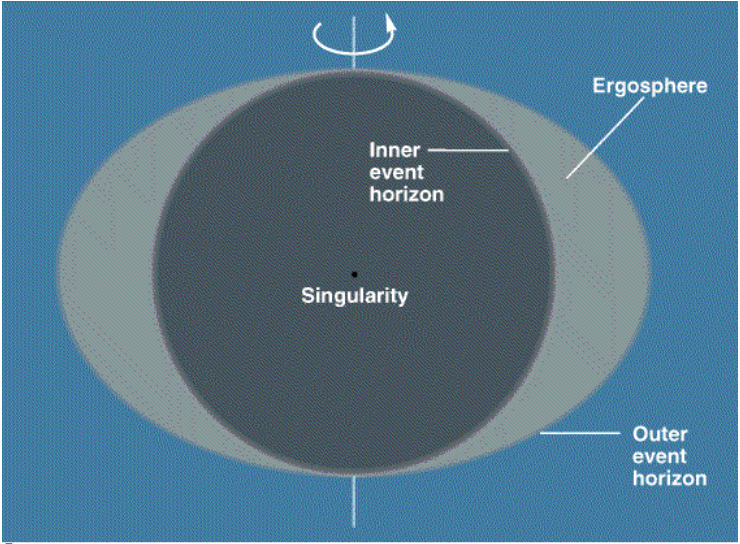
Black Holes

No Hair Theorem:
To an external observer, the black hole is completely described by 3 parameters

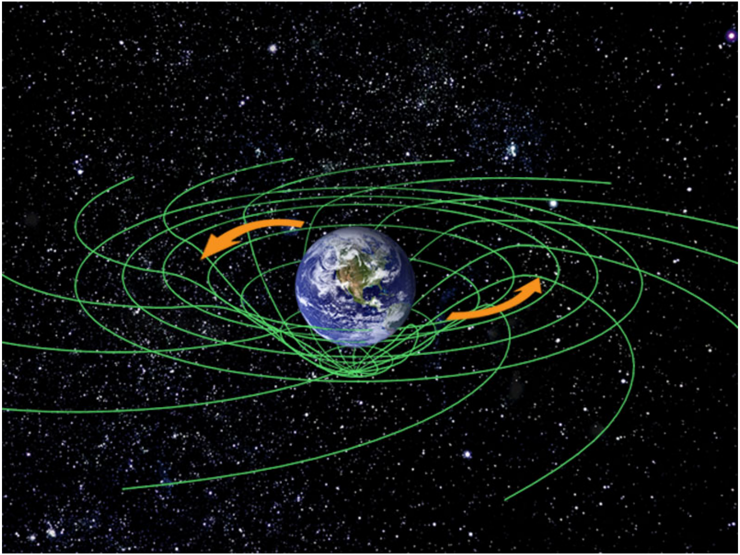
- Mass
- Electric Charge
- Spin/Angular Momentum



Spinning Black Holes



Frame Dragging



Black Holes

How do we find Black Holes?

Black Holes

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- Gravitational Lensing

Black Holes

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- Gravitational Lensing
- Gravitational Radiation

Black Holes

How do we find Black Holes?

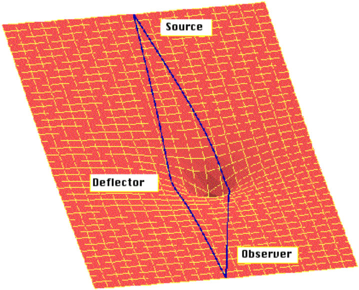
- Gravitational Lensing
- Gravitational Radiation
- Look for lots of mass in a little space

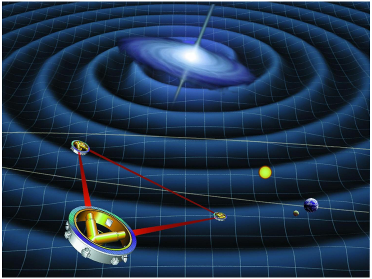
Black Holes

How do we find Black Holes?

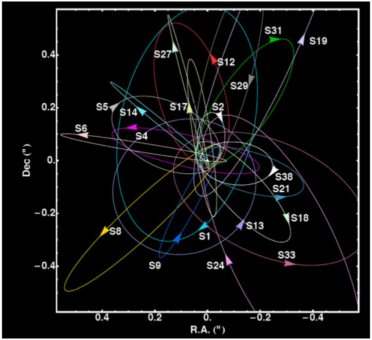
- Gravitational Lensing
- Gravitational Radiation
- Look for lots of mass in a little space
- Look for its disk

Black Holes





Black Holes


S31
S19
S27
S12
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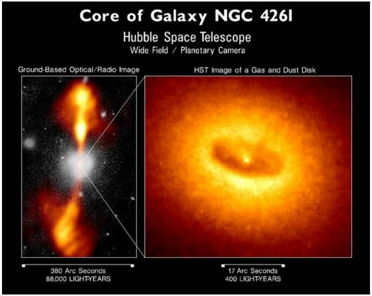
S21
S18
S13
S8
S1
S9
S24
S33
Dec (")
R.A. (")
0.4
0.2
0.
−0.2
−0.4


Core of Galaxy NGC 4261
Hubble Space Telescope
Wide Field / Planetary Camera
Ground-Based Optical/Radio Image
HST Image of a Gas and Dust Disk
380 Arc Seconds
88,000 LIGHTYEARS
17 Arc Seconds
400 LIGHTYEARS