

# Physics 100 - March 26, 2007

## Presentation Schedule

April ~~8~~

16 17, Solar System Formation

18 2, nucl. bombs - 6, GPS - 18, Football

23 24A, Feynman - 23, comets MASS ext.

25 24, Galileo - 26, Music

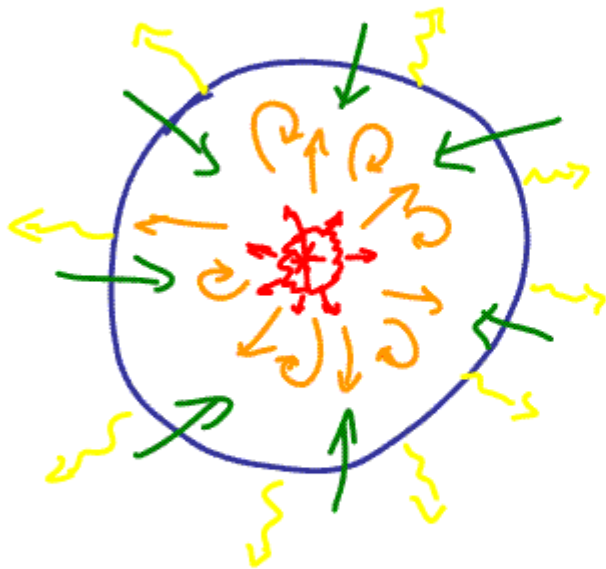
EXAM 2 in 2 weeks → April 9

During regular class time in Hoyt  
Probably similar to EXAM 1 in form  
Index card w/ formulas/notes ok  
Calculator  
Formula sheet  
Next week's recitations → mostly review

Will try to move  
to April 11  
Due to  
Proximity  
to  
Easter  
... STAY  
Tuned.

last time

intimate relation between the large  
+ small drive the stars and  
synthesize the elements



- gravity pulls in
- heat (radiation pressure) pushes out
- "Thermonuclear" fusion reactions in core
- STARTS w/  $H \rightarrow He$  but can work way up to  $^{56}Fe$
- Heavier elements formed in Supernovae
- white dwarfs, neutron stars, Black Holes

Rotation comes from  
Conservation of  
"Angular Momentum"

Pages 8-26 in Hobson - nice brief review  
of highlights of human view of  
universe and Earth's place in it



Sir Isaac Newton  
1643-1727  
(England)

universal law of gravitation

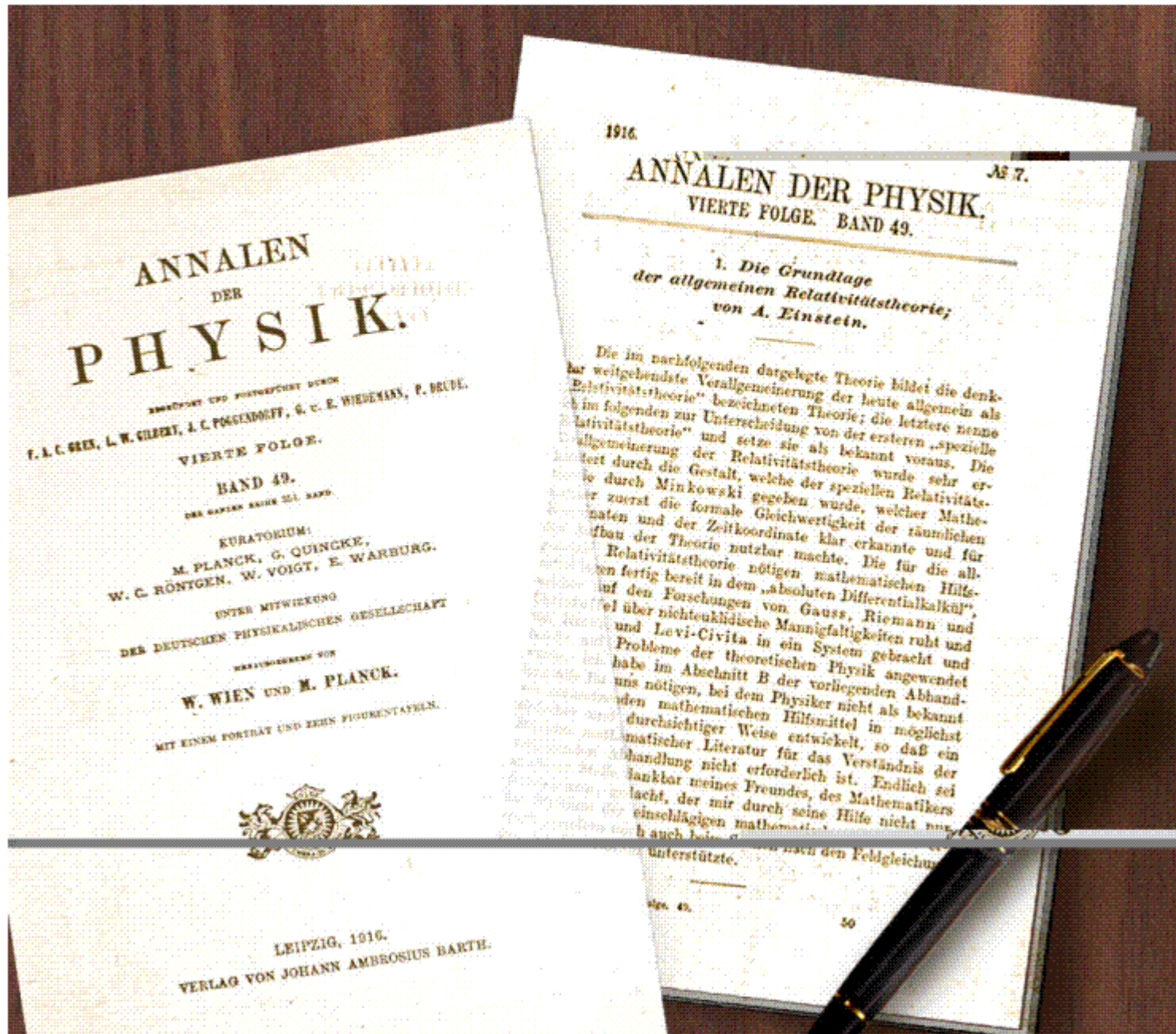
$$F = G \frac{M_1 M_2}{r^2}$$

+

Laws of Motion

⇒ derived Kepler's  
3 laws of planetary motion

# The Theory of General Relativity - Einstein 1916



## ANNALEN DER PHYSIK.

HERAUSGEGEBEN VON  
F. A. C. SIEK, L. W. GILBERT, J. C. POGGENDORFF, G. v. E. WIEDEMANN, P. BRUEHL.

VIERTE FOLGE.

BAND 49.

DREI HAFTEEN JEWEILS ZWEI BÄNDE.

KURATORIUM:

M. PLANCK, G. QUINCKE,  
W. C. RÖNTGEN, W. VOIGT, E. WARBURG.

UNTER MITWIRKUNG

DES DEUTSCHEN PHYSIKALISCHEN GESELLSCHAFT

HERAUSGEGEBEN VON

W. WIEN UND M. PLANCK.

MIT EINEM PORTRÄT UND ZEHN FIGURENTAFELN.



LEIPZIG, 1916.  
VERLAG VON JOHANN AMBROSIOUS BARTH.

1916.

NR. 7.

## ANNALEN DER PHYSIK.

VIERTE FOLGE. BAND 49.

### 1. Die Grundlage der allgemeinen Relativitätstheorie; von A. Einstein.

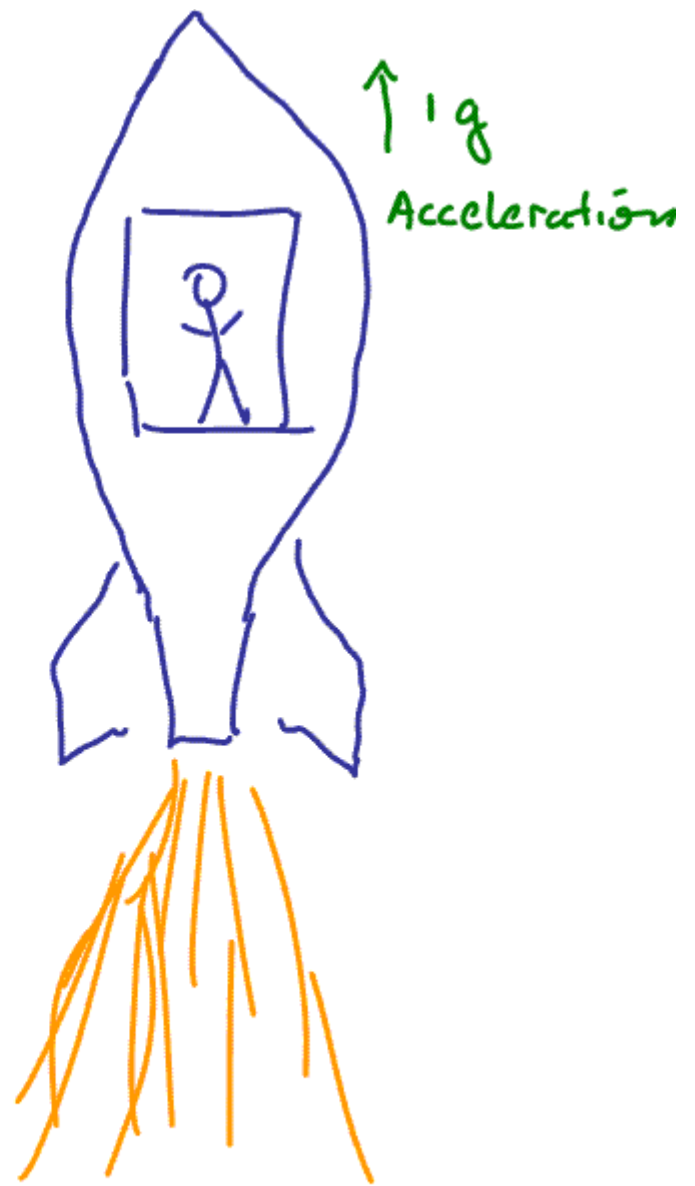
Die im nachfolgenden dargelegte Theorie bildet die denkbar weitgehendste Verallgemeinerung der heute allgemein als "Relativitätstheorie" bezeichneten Theorie; die letztere nenne ich im folgenden zur Unterscheidung von der ersteren "spezielle Relativitätstheorie" und setze sie als bekannt voraus. Die Verallgemeinerung der Relativitätstheorie wurde sehr erleichtert durch die Gestalt, welche der speziellen Relativitätstheorie durch Minkowski gegeben wurde, welcher Mathematiker zuerst die formale Gleichwertigkeit der räumlichen Koordinaten und der Zeitkoordinate klar erkannte und für den Aufbau der Theorie nutzbar machte. Die für die allgemeine Relativitätstheorie nötigen mathematischen Hilfsmittel sind fertig bereit in dem "absoluten Differentialkalkül", welcher auf den Forschungen von Gauss, Riemann und Christoffel über nichteuklidische Mannigfaltigkeiten ruht und von Ricci und Levi-Civita in ein System gebracht und in die Probleme der theoretischen Physik angewendet wurde. Ich habe im Abschnitt B der vorliegenden Abhandlung die nötigen, bei dem Physiker nicht als bekannt vorausgesetzten mathematischen Hilfsmittel in möglichst durchsichtiger Weise entwickelt, so daß ein Zuhörer mathematischer Literatur für das Verständnis der vorliegenden Abhandlung nicht erforderlich ist. Endlich sei mir die dankbar meines Freundes, des Mathematikers Dr. Hermann Weyl, erlaubt, der mir durch seine Hilfe nicht nur die mathematischen einschlägigen mathematischen Hilfsmittel, sondern auch die Unterstützung durch den Feldgleichungen..."

S. 49.

50



vs



accelerated reference frames

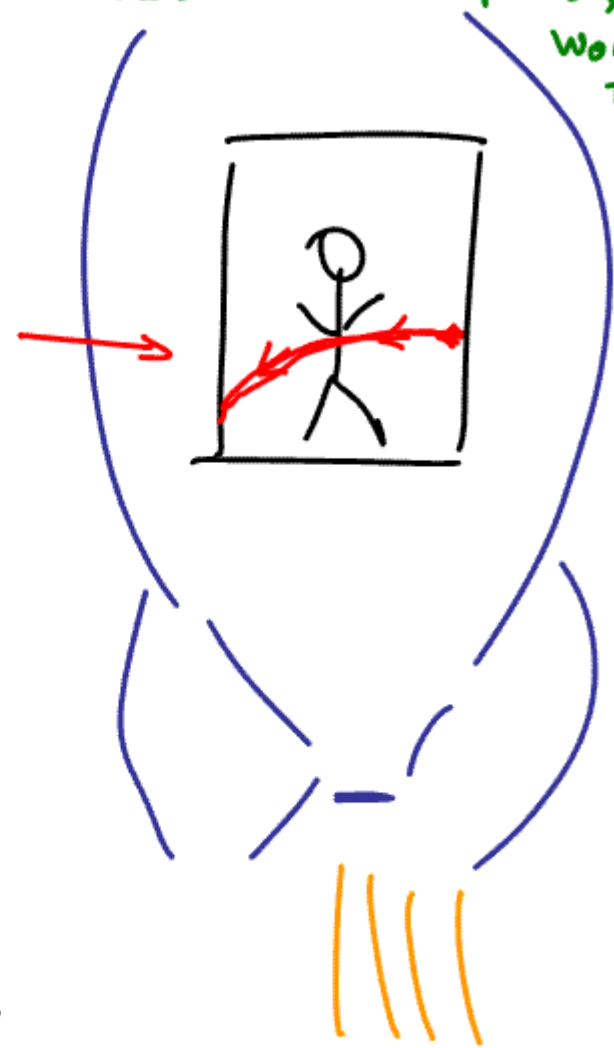
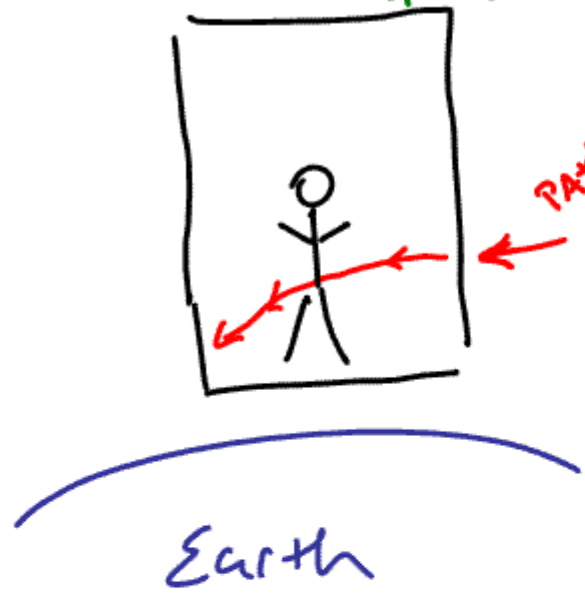
|||

gravitational field

If you are in a closed box —  
you can't tell if you are at rest on earth's surface or  
accelerating in a rocket at  $1g$ .

Equivalence of gravity  $\Leftarrow$   
Means grav. field must curve spacetime

In accelerated rocket ship case, light would seem to travel on curved path

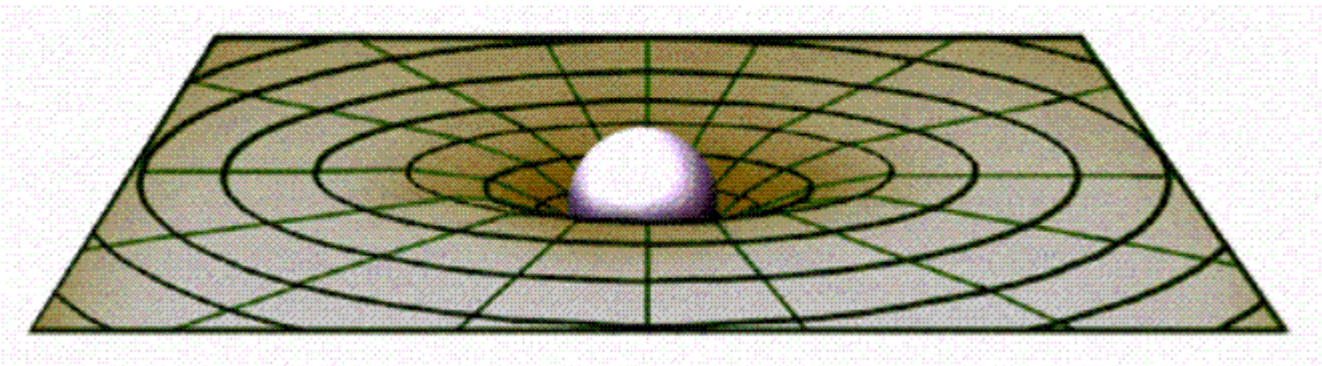
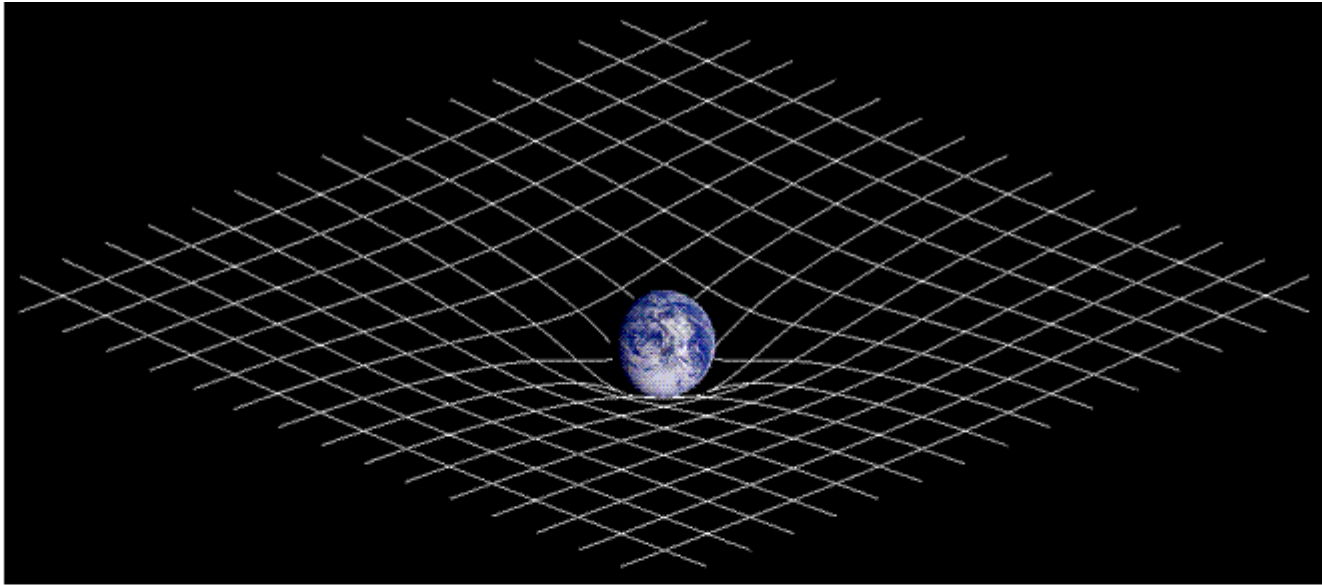


GRAV  $\equiv$  Accel. frame

light moves on a geodesic  $\uparrow$

Shortest dist. between two points

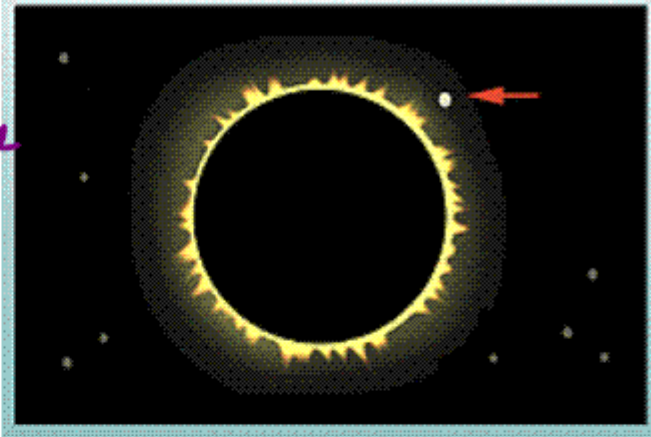
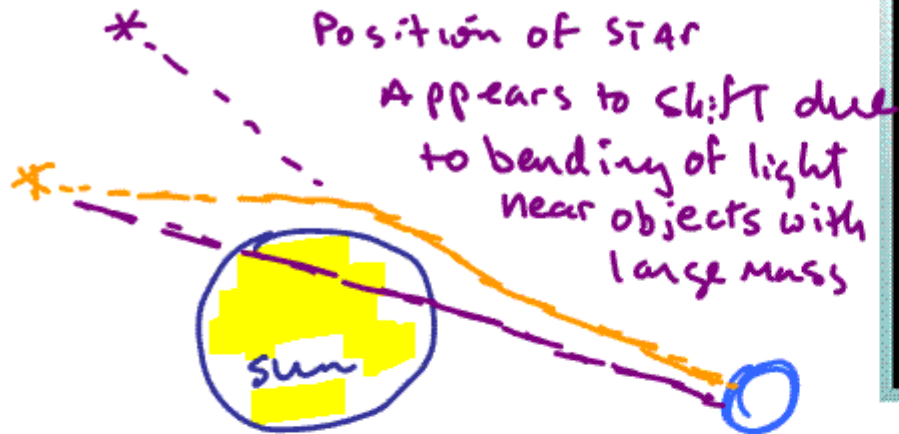
So, Einstein interprets gravitation as a curvature of spacetime



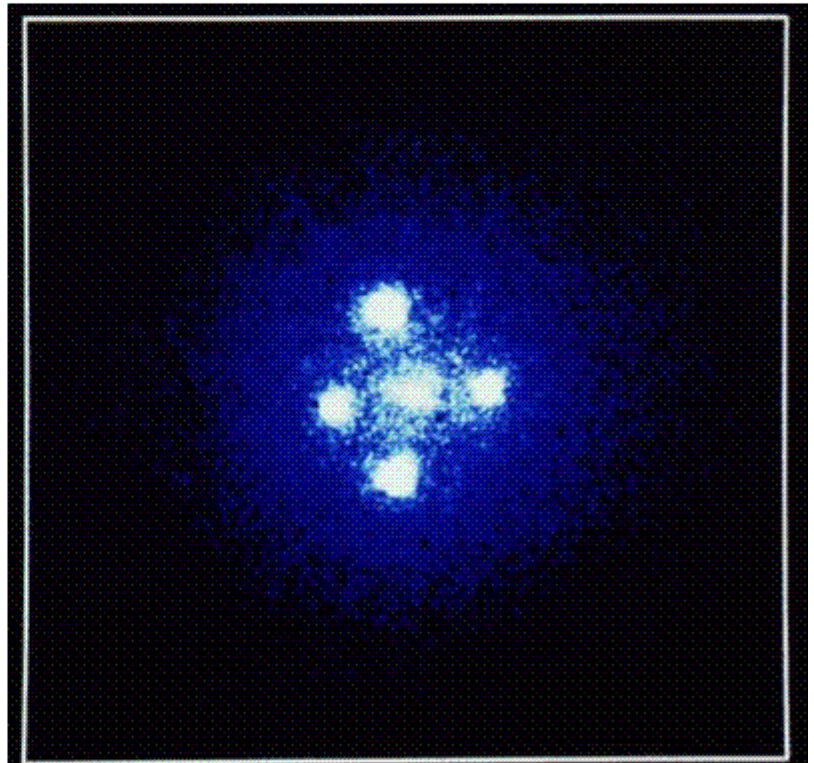
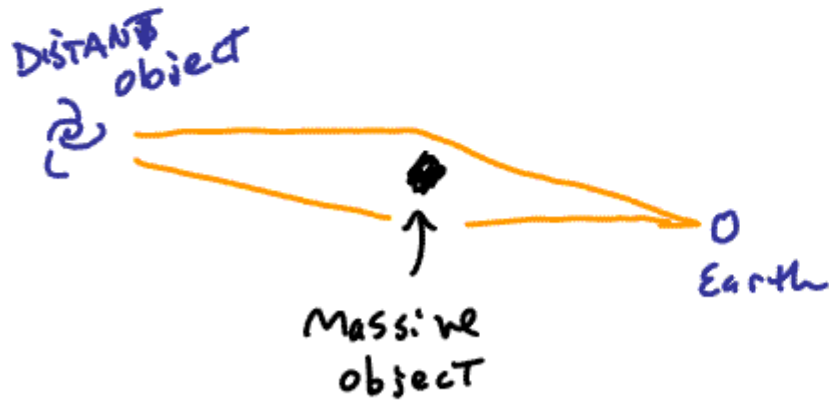
Imagine that mass causes curvature / depression in the fabric of spacetime ... is it true??

# Experimental evidence supporting General Relativity

## BENDING LIGHT

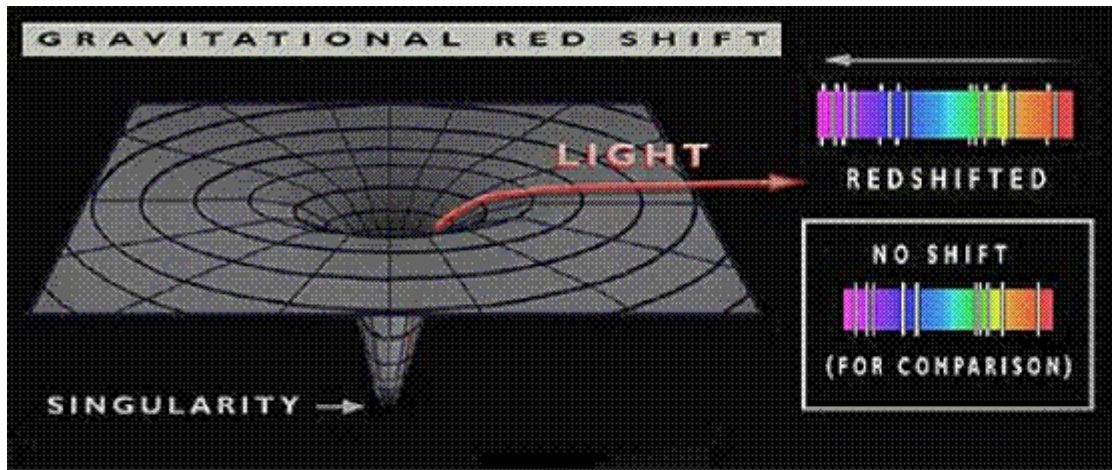


## Gravitational Lensing



Gravitational Lens G2237+0305





Spectral lines shifted to lower frequency as light leaves massive object  
 → observed for STARS and Earth.

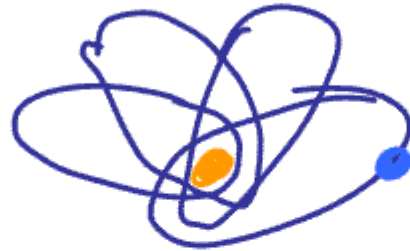
Light loses energy fighting its way out of gravitational "well"

frequency shifts lower  
 wavelength becomes longer

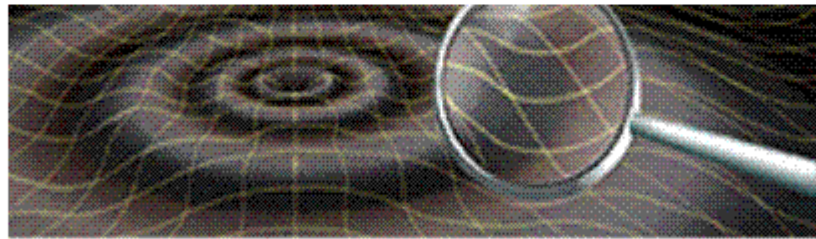
Stronger gravity → more of a redshift

G.R. needed to understand fine details of planetary orbits

Perihelion Advance of Mercury  
(show animation)



G.R. predicts existence of waves traveling in the fabric of spacetime  $\rightarrow$  gravitational waves



grav. waves would be very small distortions in spacetime traveling at speed of light from large gravitational disturbances

gravitational waves

major experiment  $\rightarrow$  LIGO  
aiming to detect grav. waves

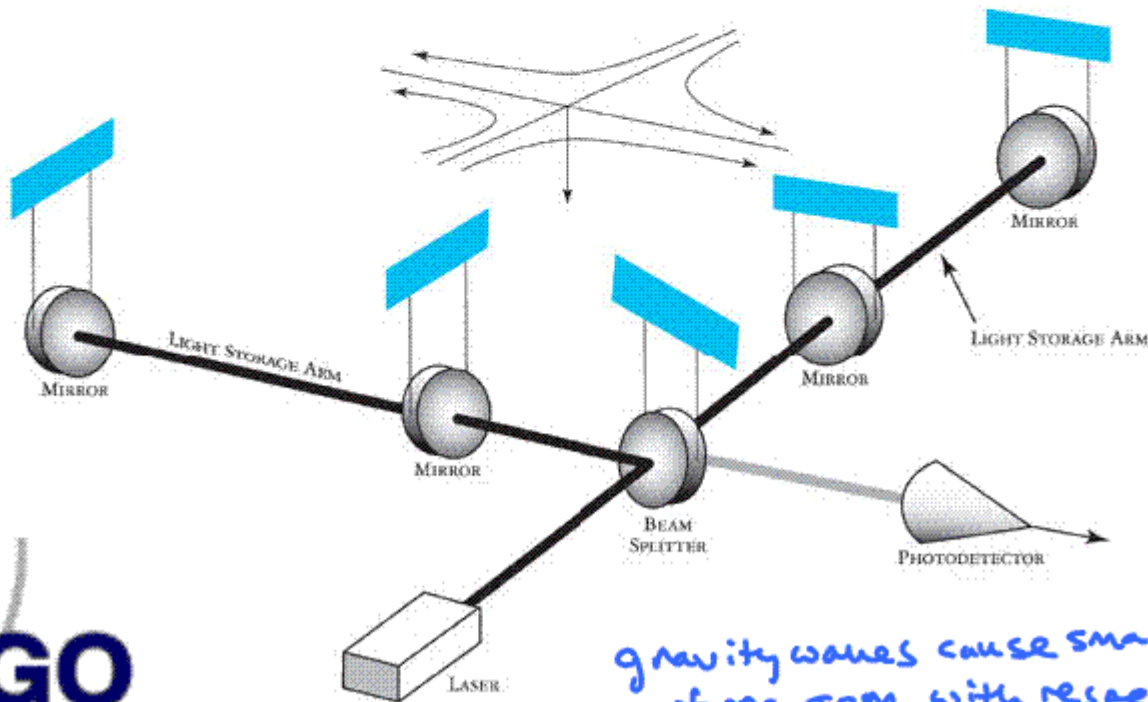
# LIGO - Laser Interferometer Gravitational Wave Observatory

<http://www.ligo.caltech.edu/>

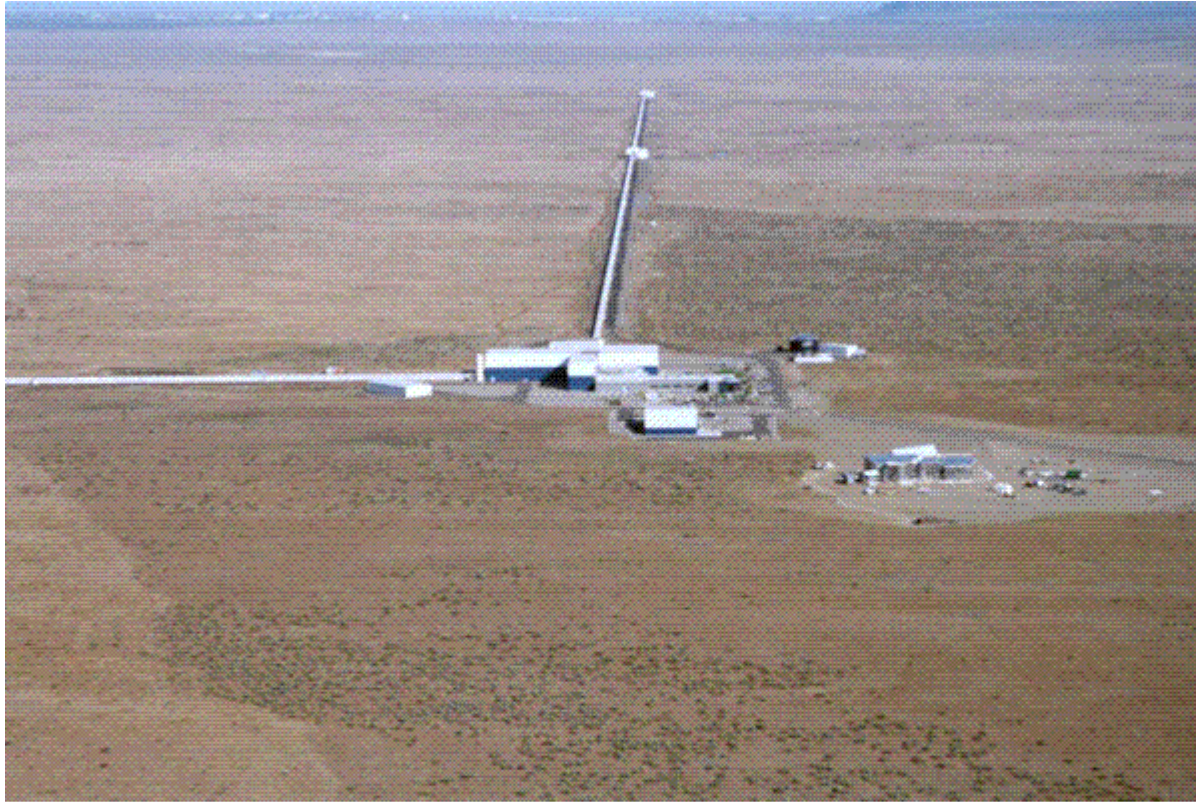


Distortions  
 $\sim 10^{-16}$  m

Arms  
 $\sim 4$  km  
in length



gravity waves cause small distortions  
of one arm with respect to  
the other.



LIGO Site in Hanford, WA  
Also one in Louisiana



There are other projects ...

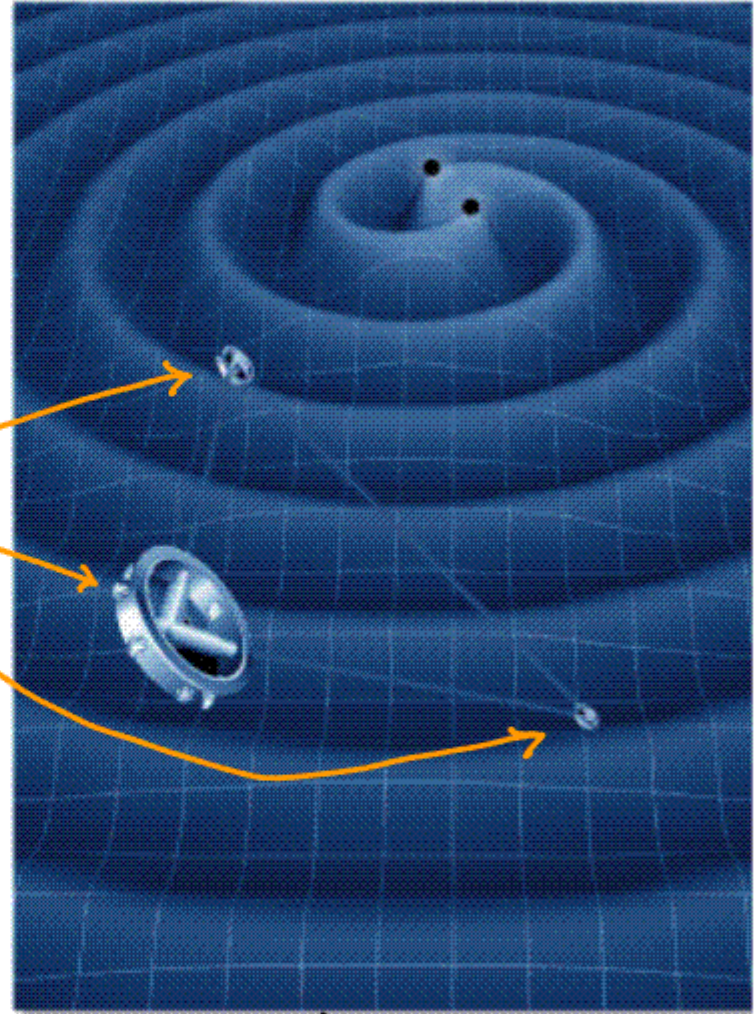
## LISA

Laser Interferometer

SPACE antenna

ESA + NASA

3 satellites widely  
separated in space —  
idea is to watch how  
the distance between them  
varies as the gravitational  
Wave passes by



perhaps someday we will be able to study astrophysical  
objects by observing emitted grav. waves → gravitational  
wave astronomy

# Places to learn more: Particle and nuclear physics links

<http://pdg.lbl.gov>

<http://particleadventure.org>

<http://www.slac.stanford.edu/gen/edu/aboutslac.html>

<http://www.bnl.gov/bnlweb/sciindex.html>

<http://www.bnl.gov/rhic/>

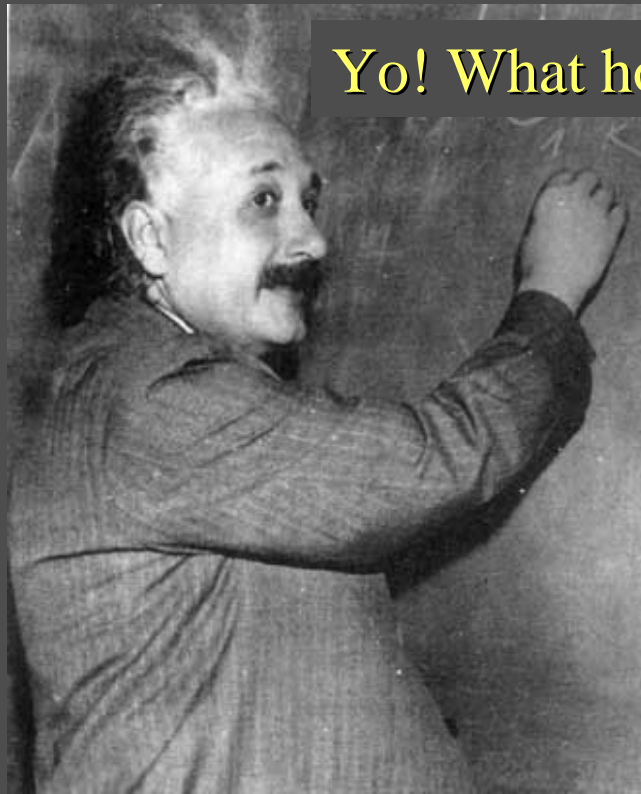
<http://public.web.cern.ch/public/>

<http://www.fnal.gov/>

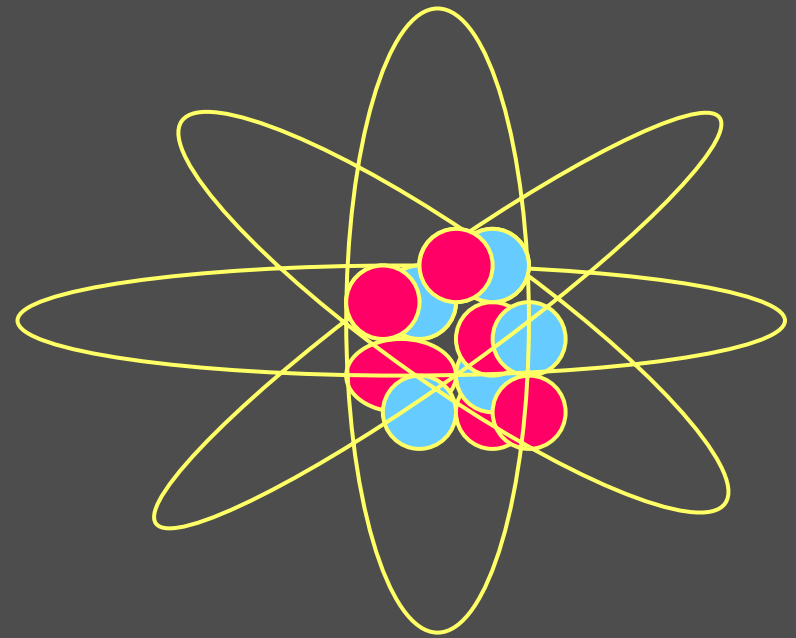
<http://www.er.doe.gov/production/henp/np/index.html>

<http://www.science.doe.gov/hep/index.shtm>

# Inquiring minds want to know ...



Yo! What holds it together?



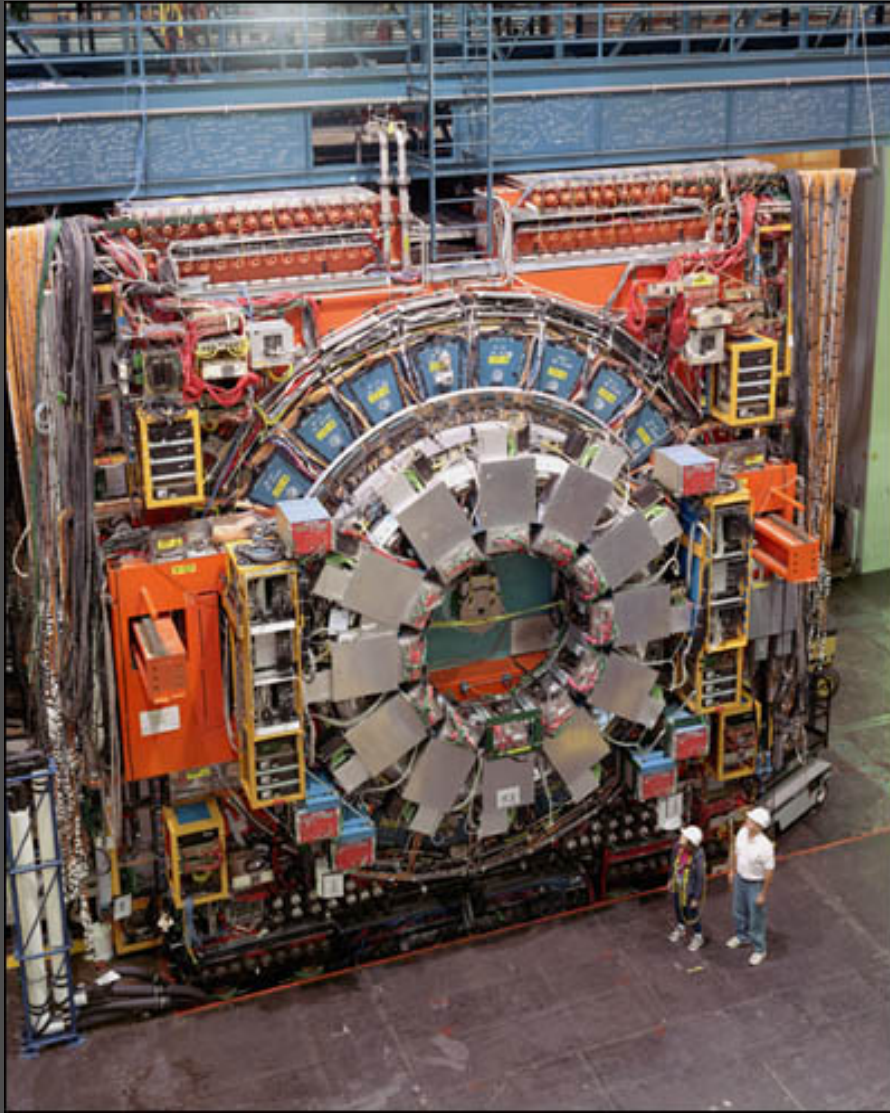




# Fermi National Accelerator Laboratory (near Chicago)



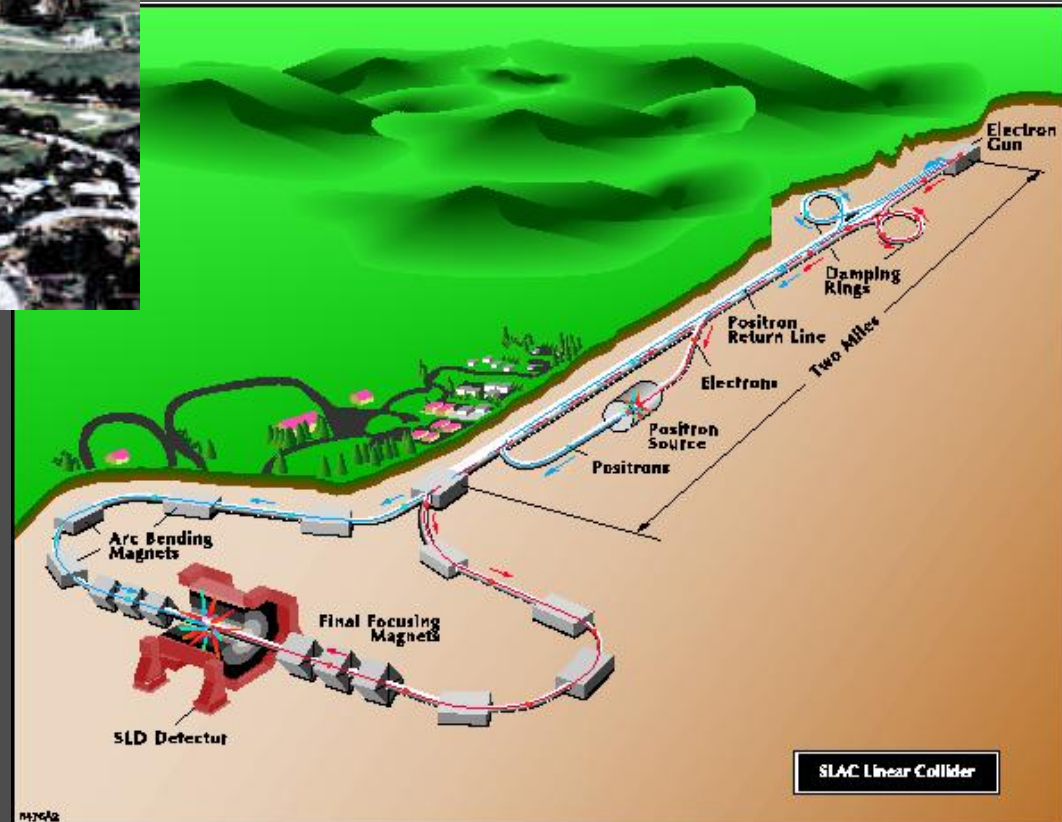
CDF



Minos



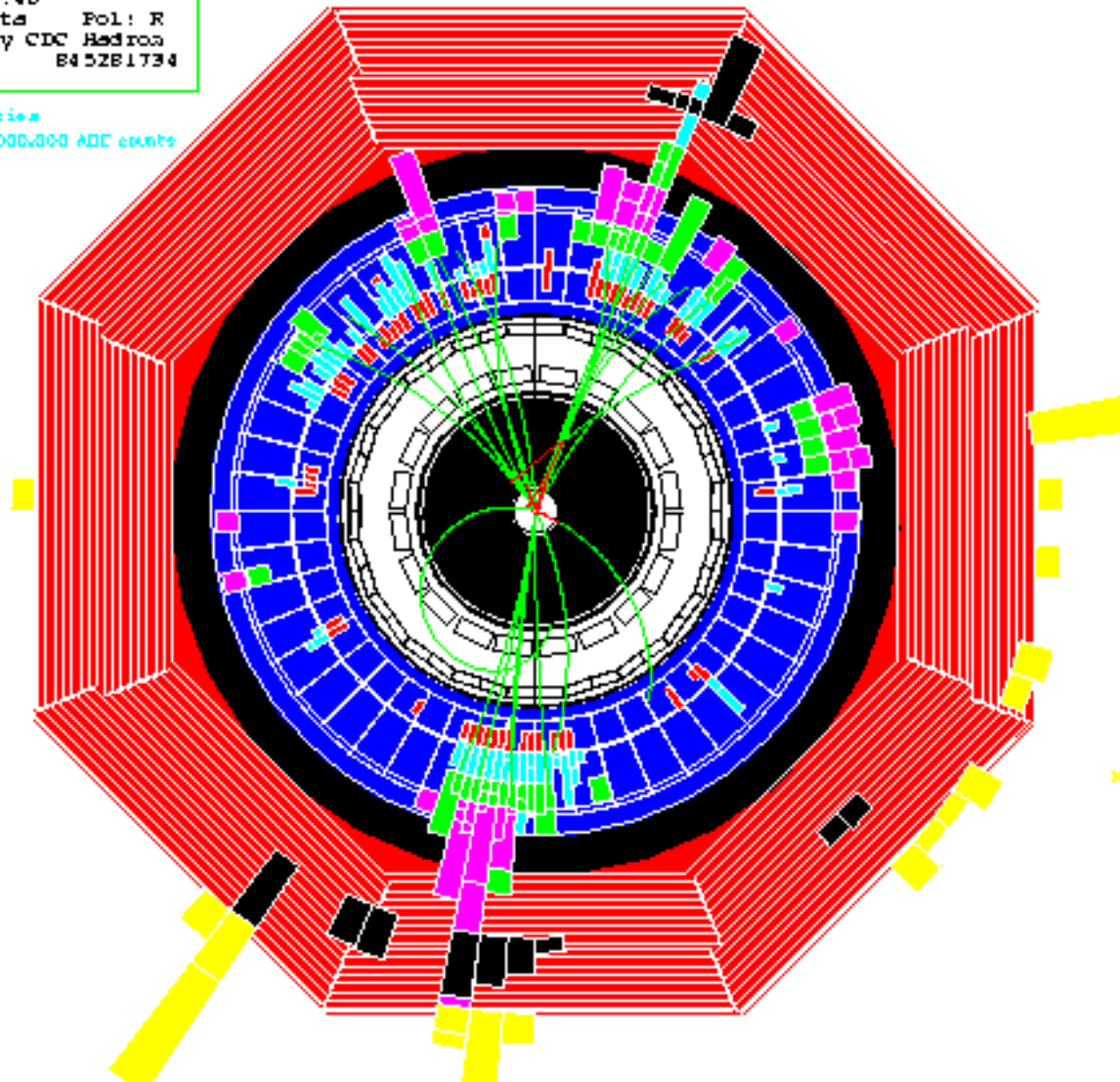
# Stanford Linear Accelerator Center



# Event display from the SLD experiment at SLAC

Run 2057E, EVENT 779  
23-MAR-1993 12:40  
Source: Run Data Fol: R  
Trigger: Energy CDC Hadron  
Beam Crossing 845281734

Xal hit properties  
5.026 <math>E\_{had}</math> <math>15000/000</math> ADC counts



XAL Subsystems  
XAL 0  
XAL 1  
LAC IN1  
LAC IN2  
LAC RAD1  
LAC RAD2  
MIC 1  
MIC 2



$$I^G(J^{PC}) = 1^-(0^{-+})$$

Mass  $m = 134.9766 \pm 0.0006$  MeV ( $S = 1.1$ )

$m_{\pi^+} - m_{\pi^0} = 4.5936 \pm 0.0005$  MeV

Mean life  $\tau = (8.4 \pm 0.6) \times 10^{-17}$  s ( $S = 3.0$ )

$c\tau = 25.1$  nm

For decay limits to particles which are not established, see the appropriate Search sections ( $A^0$  (axion), and Other Light Bosons ( $X^0$ ) Searches, etc.).

week ending  
4 JUNE 2004

$\rightarrow \omega\gamma(1S)$

E. Coan,<sup>2</sup> Y.S. Gao,<sup>2</sup> F. Liu,<sup>2</sup>  
Dorjkhaidav,<sup>3</sup> R. Mountain,<sup>3</sup>  
Mahmood,<sup>4</sup> S.E. Csorna,<sup>5</sup>  
Das,<sup>7</sup> A. Shaikro,<sup>7</sup> W.M. Sun.<sup>7</sup>

S 30 MARCH 1998

ISS

mendolia,<sup>27</sup> D. Amidei,<sup>20</sup> J. Antos,<sup>33</sup>  
<sup>8</sup> M. Atac,<sup>7</sup> P. Azzi-Bacchetta,<sup>25</sup>

1 MARCH 1999

Measurement  
of  $\pi^0$  radiative decay

Itow,<sup>1</sup> T. Kajita,<sup>1</sup> J. Kameda,<sup>1</sup>  
and S. Nishimura,<sup>1</sup> A. Oishi,<sup>1</sup>

26 MAY 1975

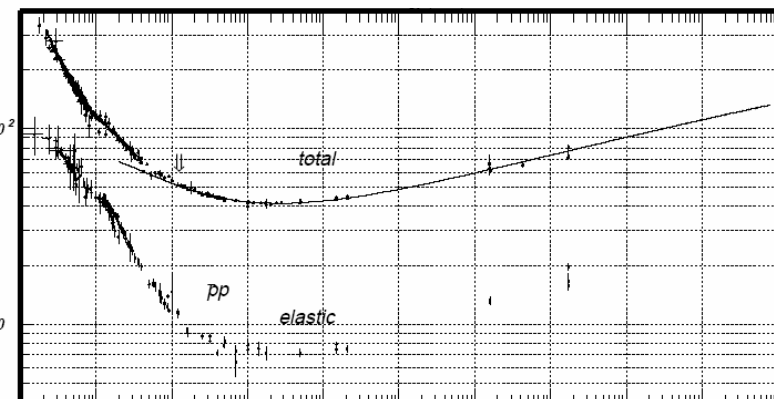
$\pi^0$ DECAY MODES	Fraction ( $\Gamma_i/\Gamma$ )	Scale factor/ Confidence level	$p$ (MeV/c)
$2\gamma$	$(98.798 \pm 0.032) \%$	$S=1.1$	67
$e^+e^-\gamma$	$(1.198 \pm 0.032) \%$	$S=1.1$	67
$\gamma$ positronium	$(1.82 \pm 0.29) \times 10^{-9}$		67
$e^+e^+e^-e^-$	$(3.14 \pm 0.30) \times 10^{-5}$		67
$e^+e^-$	$(6.2 \pm 0.5) \times 10^{-8}$		67
$4\gamma$	$< 2$	$\times 10^{-8}$ CL=90%	67
$\mu\bar{\mu}$	$< 8.3$	$\times 10^{-7}$ CL=90%	67
$\mu_0\bar{\mu}_0$	$< 1.7$	$\times 10^{-6}$ CL=90%	67
$\mu^+\mu^-\mu^+$	$< 3.1$	$\times 10^{-6}$ CL=90%	67
$\mu^+\mu^-\mu^-$	$< 2.1$	$\times 10^{-6}$ CL=90%	67
$\gamma\mu\bar{\mu}$	$< 6$	$\times 10^{-4}$ CL=90%	-

Charge conjugation (C) or Lepton Family number (LF) violating modes

$3\gamma$	C	$< 3.1$	$\times 10^{-8}$ CL=90%	67
$\mu^+e^-$	LF	$< 3.8$	$\times 10^{-10}$ CL=90%	26
$\mu^-e^+$	LF	$< 3.4$	$\times 10^{-9}$ CL=90%	-
$\mu^+e^- + \mu^-e^+$	LF	$< 1.72$	$\times 10^{-8}$ CL=90%	26

Cross section (mb)

Cross section (mb)



Laboratory beam momentum (GeV/c)

$\psi(3095)^{\dagger}$

ischer, D. Fryberger, G. Hanson,  
, D. Lyon, C. C. Morehouse,  
R. F. Schwitters,

ford, California 94305

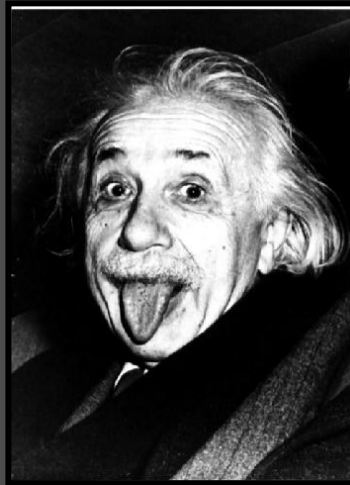
G. Golhaber, J. A. Kadyk,  
Trilling, J. S. Whitaker,

ifornia, Berkeley, California 94720

near 3095 MeV. The

What forces exist in nature?

What is a force?



How do they interact?

How do forces change with energy or temperature?

How has the universe evolved?

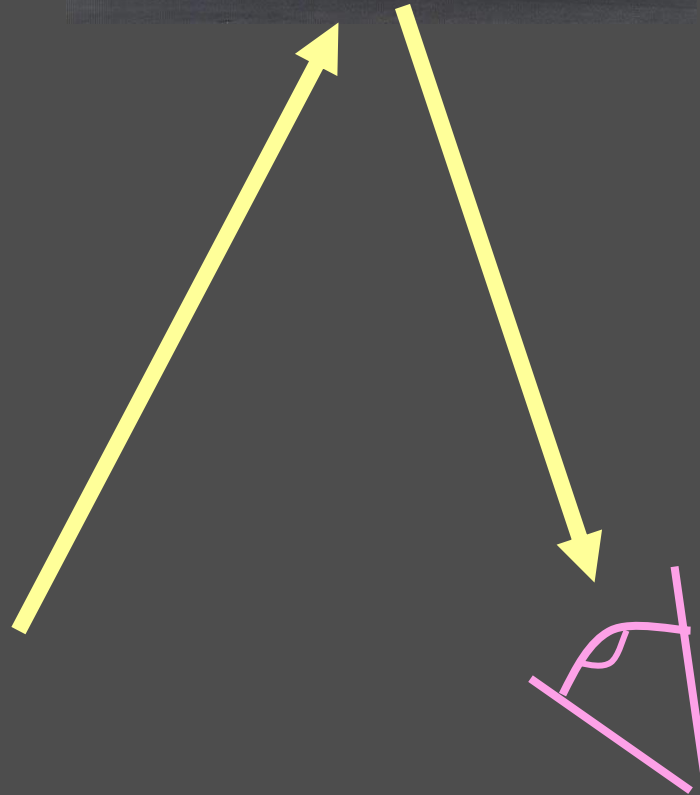
# Mini-Ph.D. – Quantum Mechanics 101

## Lesson 1:

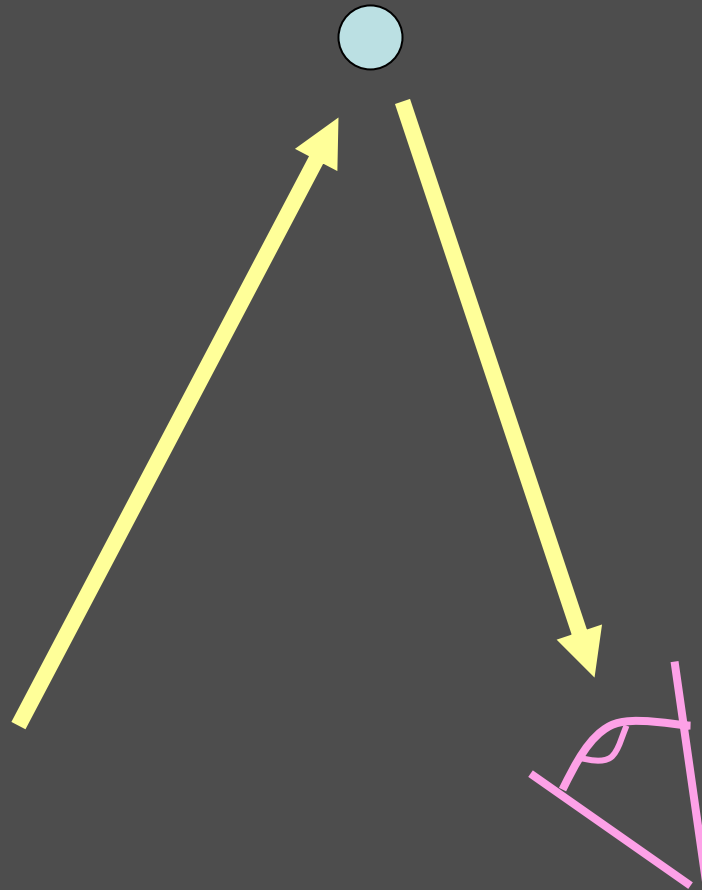
**Size actually does matter.**



Determine the position and velocity of a car ... no problem

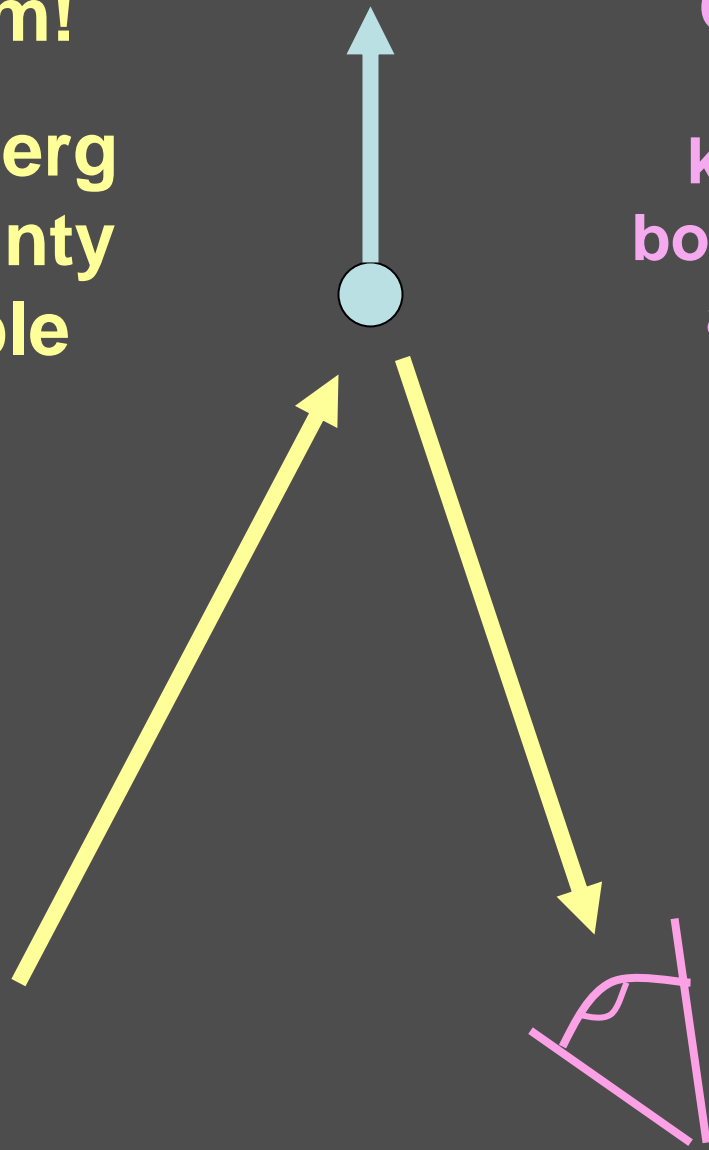


**Determine the position and velocity  
of a small particle ... no problem**



**Problem!**  
**Heisenberg**  
**uncertainty**  
**principle**

**Cannot have**  
**perfect**  
**knowledge of**  
**both the position**  
**and velocity**

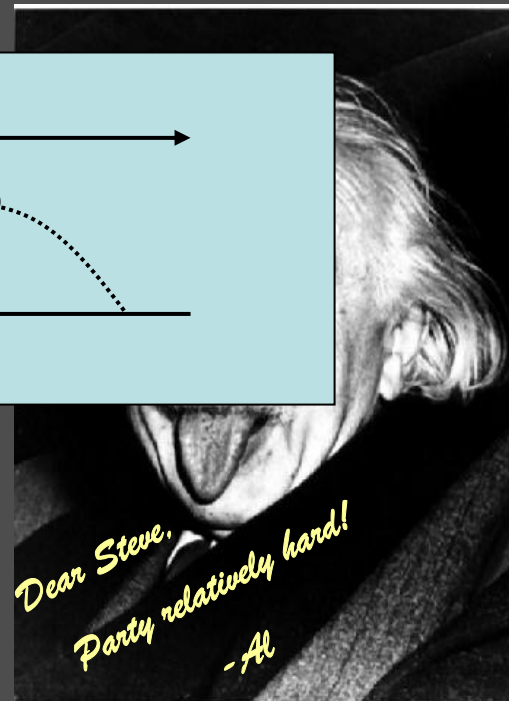
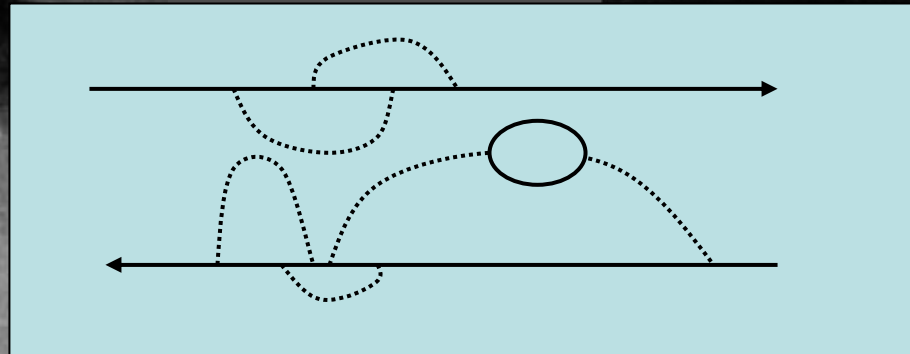
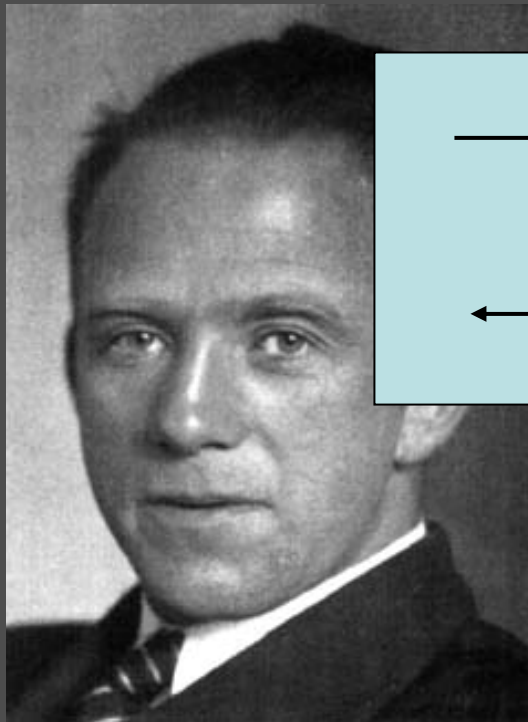
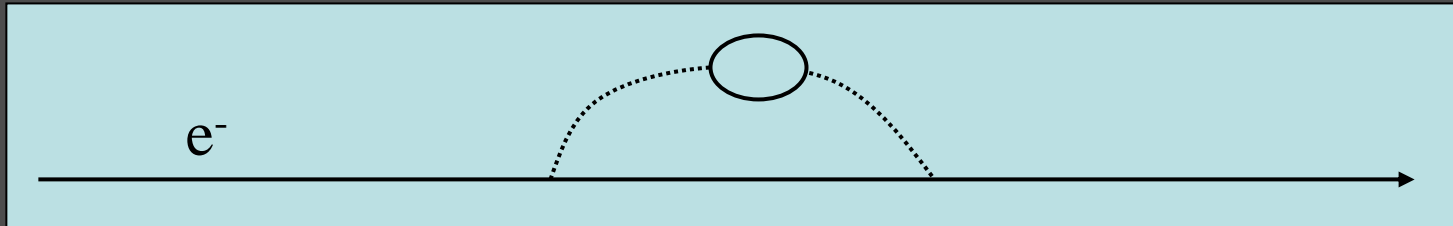


**Heisenberg**

# The fundamental nature of forces: virtual particles

$$\Delta E \Delta t \approx h \quad \text{Heisenberg}$$

$$E = mc^2 \quad \text{Einstein}$$



<i>Force</i>	<i>Source</i>	<i>Range</i>	<i>Strength</i>
<i>Gravitation</i>	mass	infinite	$10^{-39}$
<i>Electromagnetism</i>	Electric charge	infinite	$10^{-2}$
<i>Strong nuclear</i>	Color charge	$10^{-15}$ m	1
<i>Weak nuclear</i>	Weak charge	$10^{-18}$ m	$10^{-5}$

Frank and Ernest



# The Standard Model of Particle Interactions

Three Generations of Matter

I II III

Leptons Quarks

$u$ <small>up</small>	$c$ <small>charm</small>	$t$ <small>top</small>	$\gamma$ <small>photon</small>
$d$ <small>down</small>	$s$ <small>strange</small>	$b$ <small>bottom</small>	$g$ <small>gluon</small>
$\nu_e$ <small>electron neutrino</small>	$\nu_\mu$ <small>muon neutrino</small>	$\nu_\tau$ <small>tau neutrino</small>	$Z$ <small>Z boson</small>
$e$ <small>electron</small>	$\mu$ <small>muon</small>	$\tau$ <small>tau</small>	$W$ <small>W boson</small>

Force Carriers