

Physics 100 - November 12, 2007

- Exam Wednesday
- Q + A Session Tuesday 4:30-6:00
B+L 208
- Presentation Group meetings

Fundamental Particles

Fundamental Forces

Strength

Quarks

u, d, c, s, t, b

fract. electric chg
bind by st. interaction

(qqq) Baryons
Proton, neutron

$(q\bar{q})$ Mesons
 π, K

Leptons

e, μ , τ

ν_e, ν_μ, ν_τ

Gauge Bosons

mediate forces

$\gamma, W^{+/-}, Z, g$ (gluon), G (graviton)

Higgs

gravitation
Graviton

Strong
gluon
range is self-limiting

Weak
 $W^{+/-}, Z$
 10^{-18} m range

Electromagnetism
 γ
infinite range

$\sim 10^{-40}$

30

1

1

Quantum Field Theory

Weak

EM

Strong

No Mass
in
theory

Weak + EM + Higgs



Mass
W, Z, γ predicted

STANDARD Model

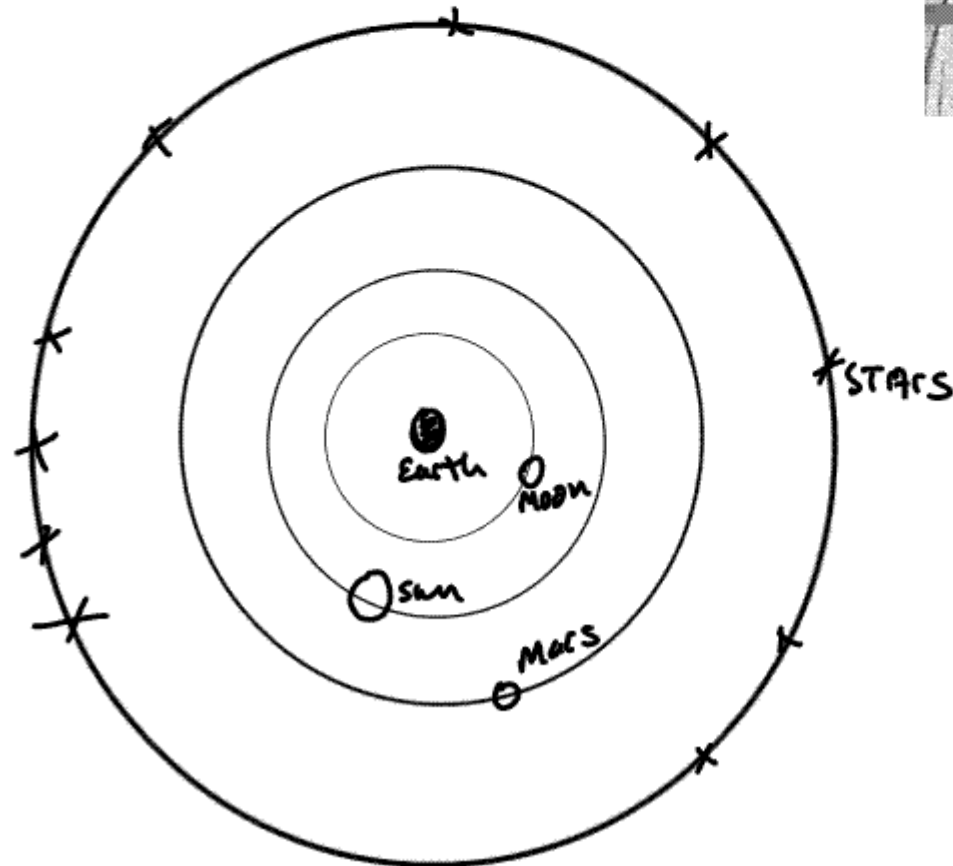
Something does what the Higgs does

Let's move from inner space to outer space

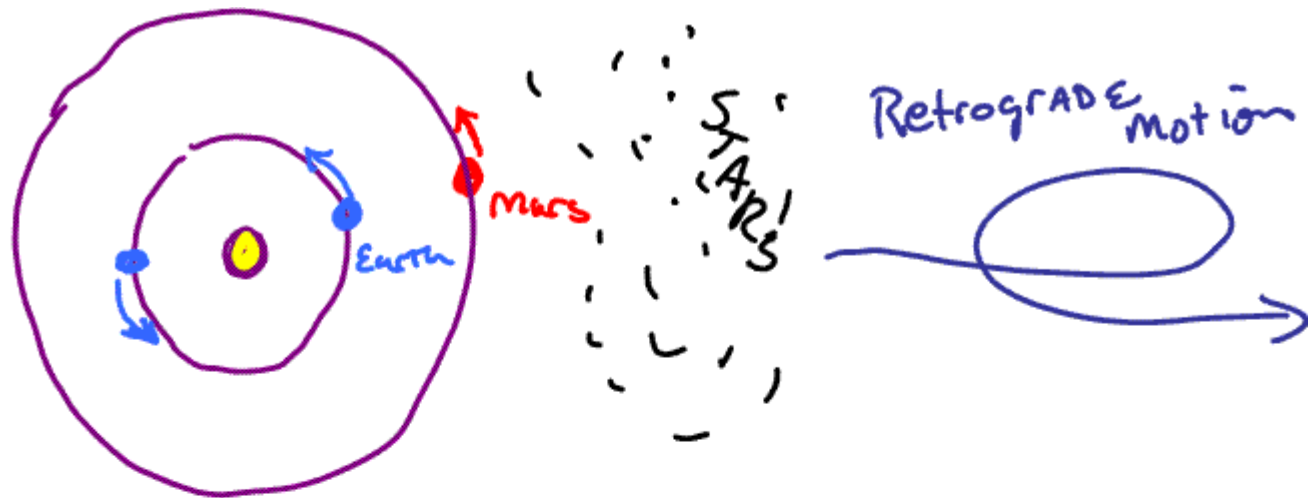
Views of Earth's place in the cosmos...

Pythagorean theory

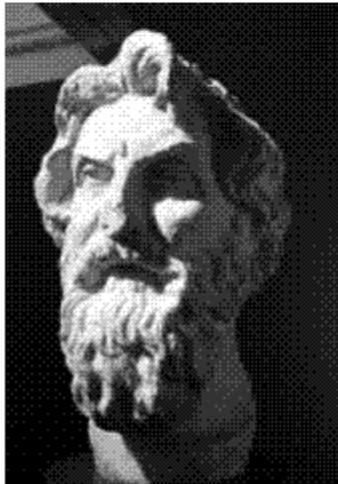
Early Greek view of the universe



Pythagoras
of
Samos
~ 500BC

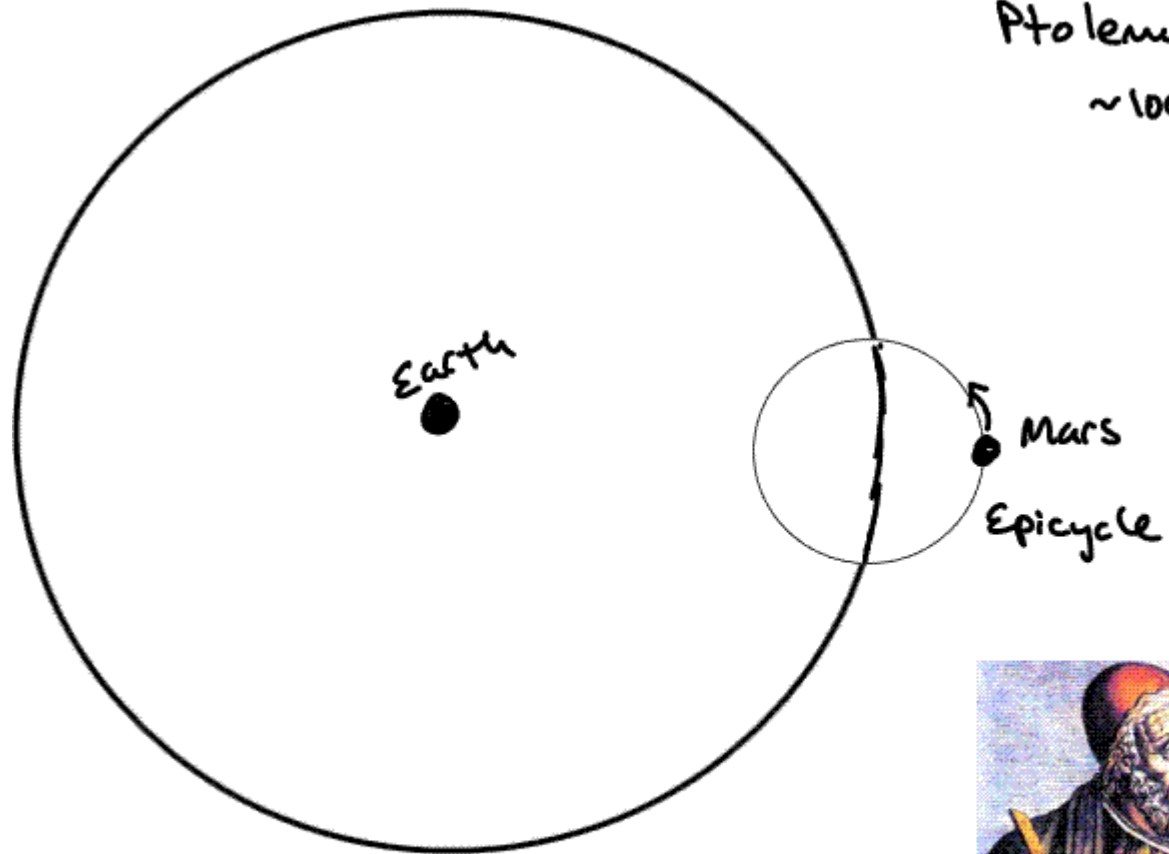


Plato ~ 400 BC ~ Multiple spheres



Aristarchus ~ 310 - 230 BC
(Greek)

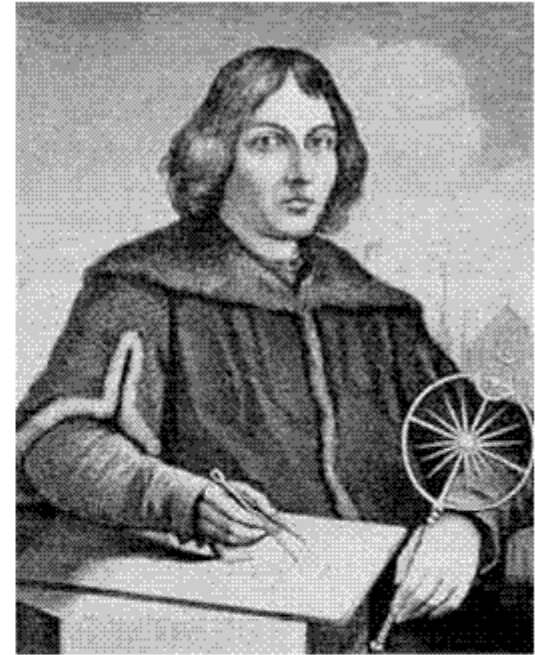
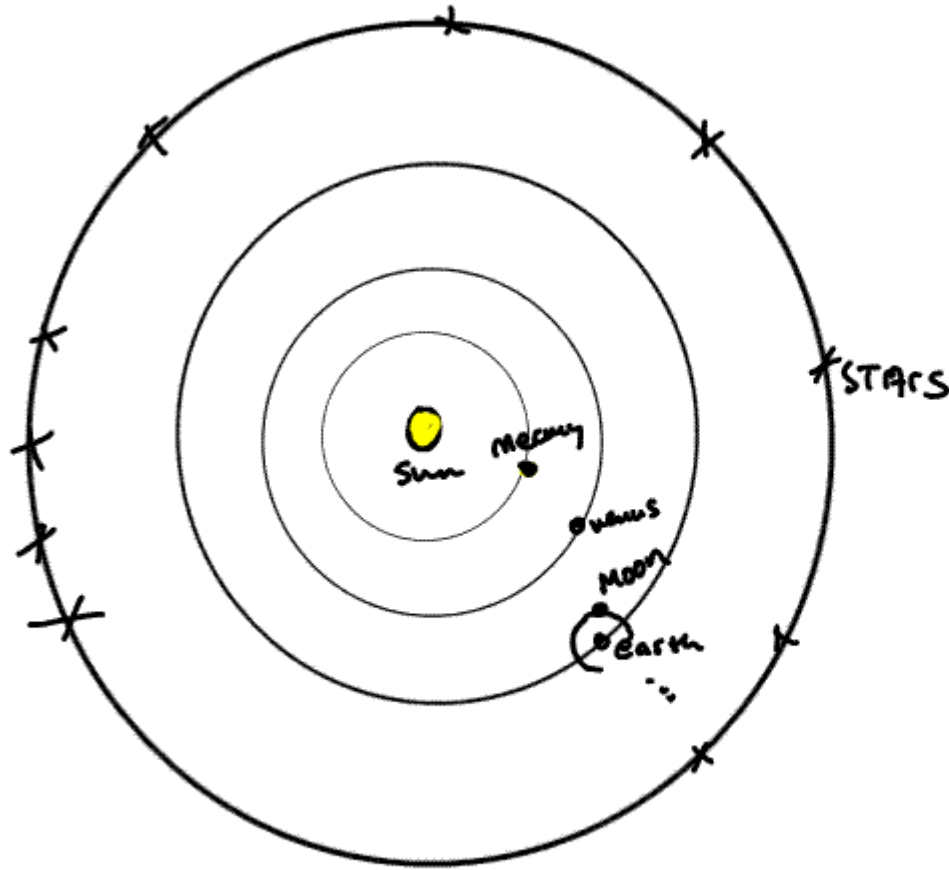
Proposed sun-centered universe
→ rejected



Ptolemy
~100 AD



Sun Centered universe



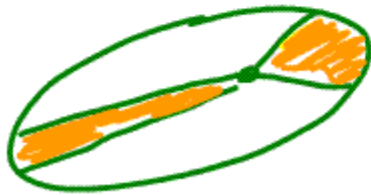
Nicolaus Copernicus
1473-1543
(Poland)

On the Revolutions of the
Heavenly Spheres

Brake's data did NOT fit perfectly
with Copernicus' theory



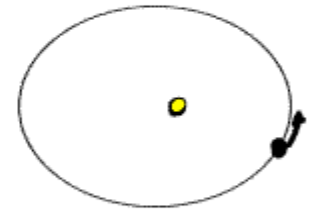
Tycho Brahe
1546-1601
(Dane)
careful observations
of positions
of sun, moon, planets



Determined 3 laws
that mathematically
describe orbits seen -
relate periods, areas, axes



Johannes Kepler
1571-1630
(German)



⇒ Elliptical orbits
fits the data!

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

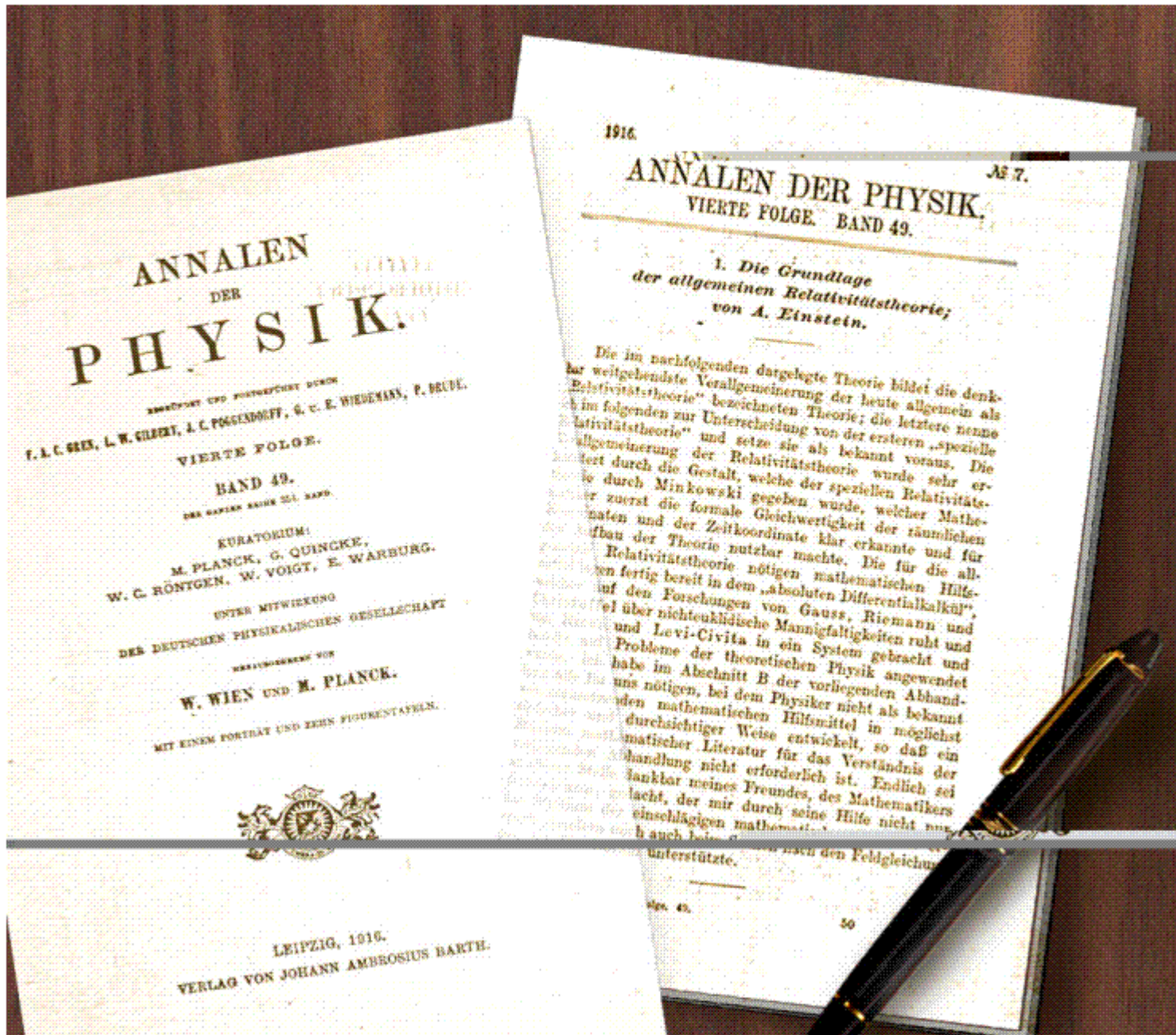
$$F = G \frac{M_1 M_2}{r^2}$$

+

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. BRUEDE.
VIERTE FOLGE.

BAND 49.

DES KARLSEN KAUER 251. BAND.

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 PORTRAIT UND ZEHN FIGURENTAFELN.



LEIPZIG, 1916.
VERLAG VON JOHANN AMBROSIOUS BARTHE.

1916.

NR. 7.

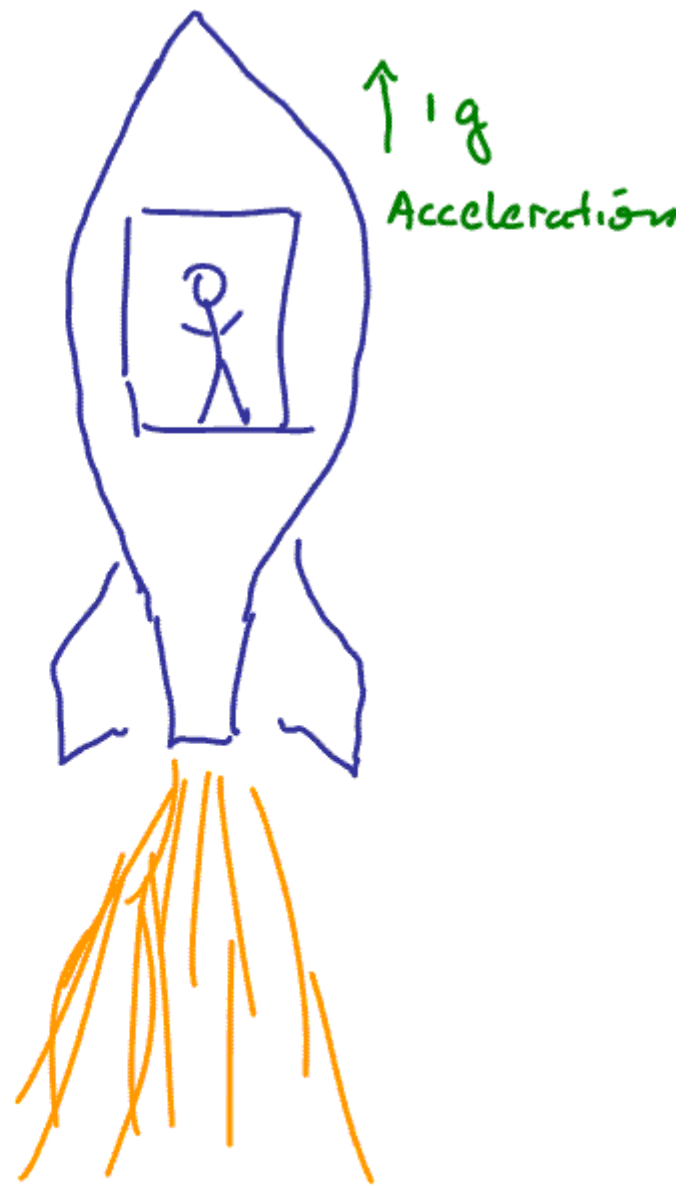
ANNALEN DER PHYSIK. VIERTE FOLGE. BAND 49.

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 Verständnis der mathematischen 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



vs



accelerated reference frames

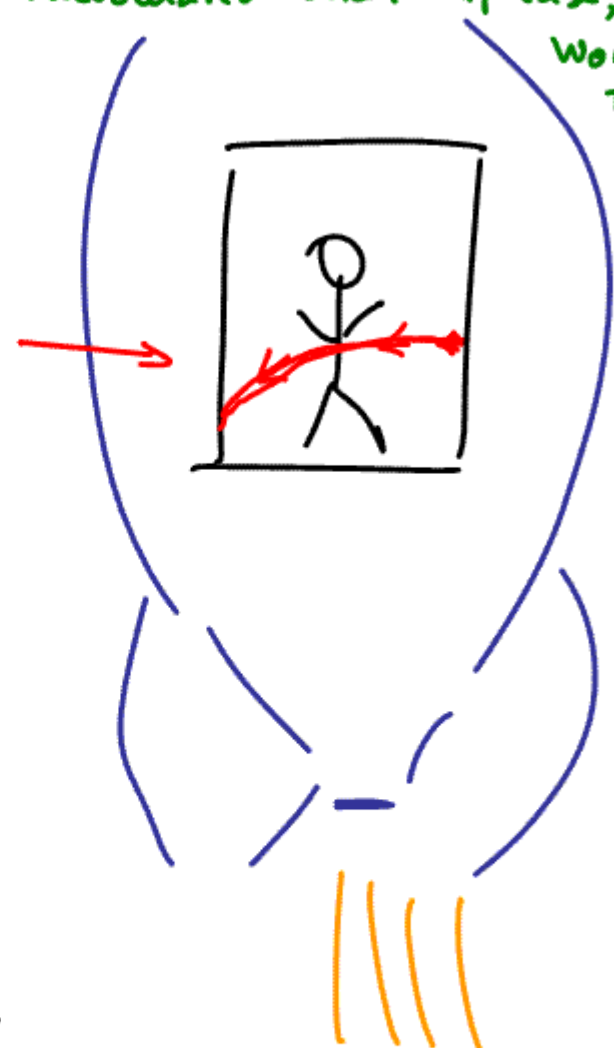
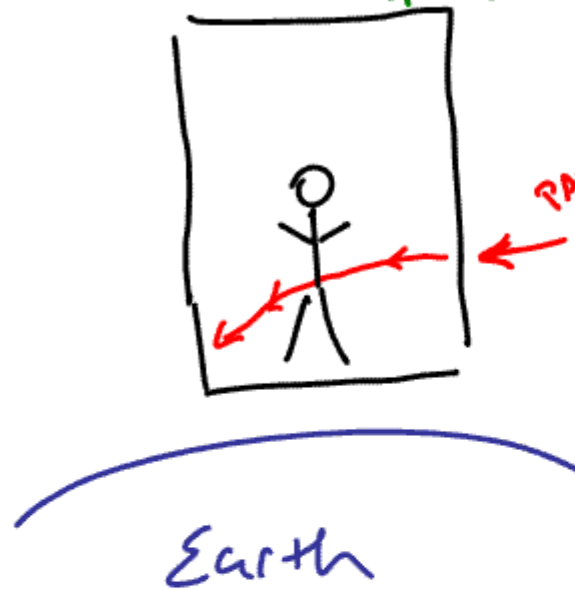
|||

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

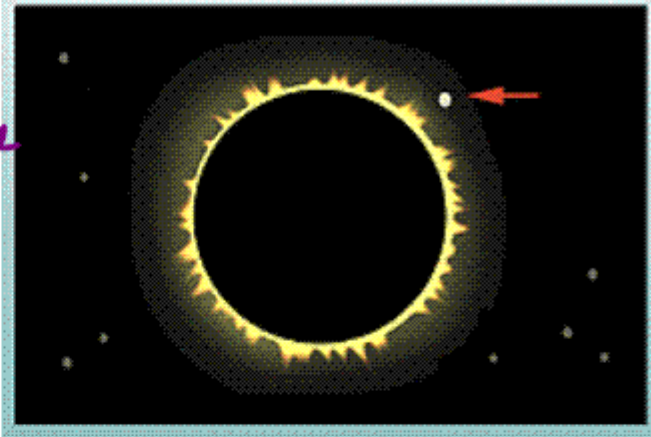
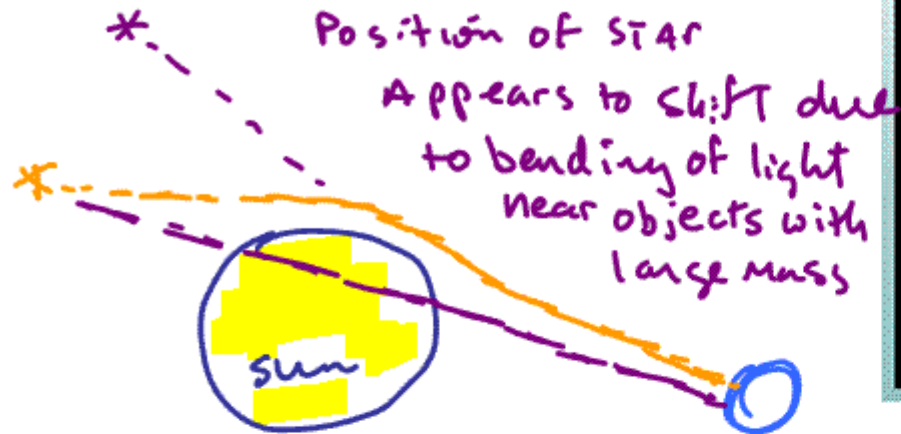
light moves on a geodesic \uparrow

Shortest dist. between two points

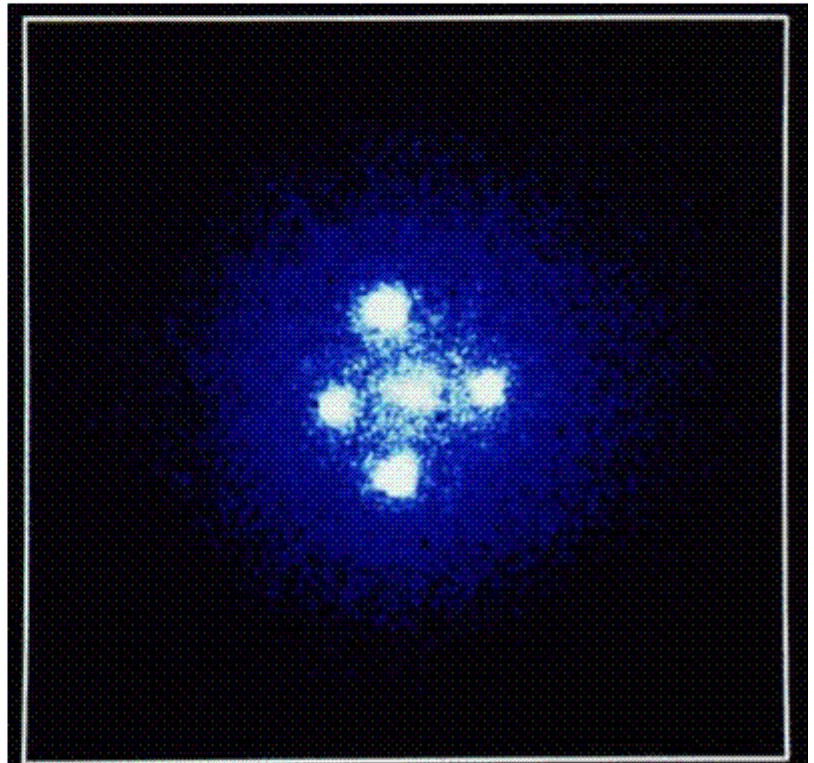
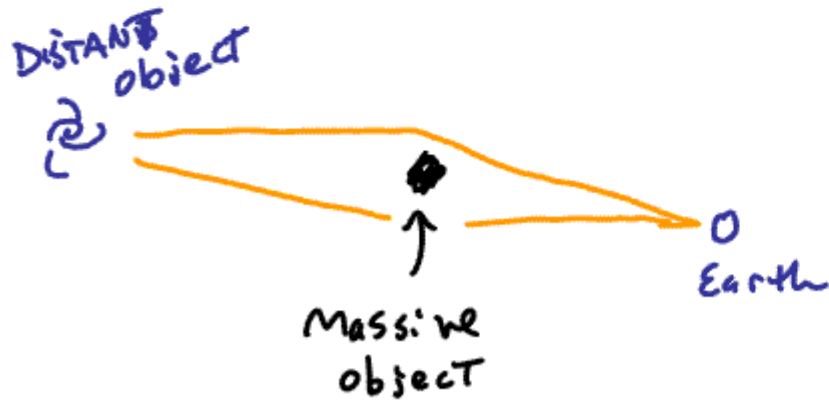
So, Einstein interprets gravitation as a curvature of spacetime

Experimental evidence supporting General Relativity

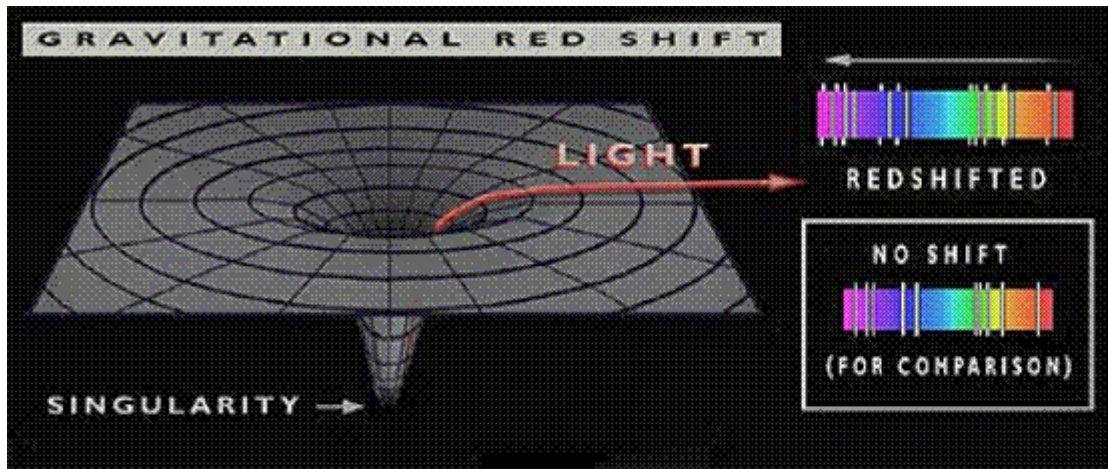
BENDING LIGHT



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"

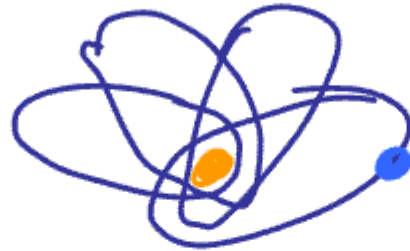
frequency shifts lower

wavelength becomes longer

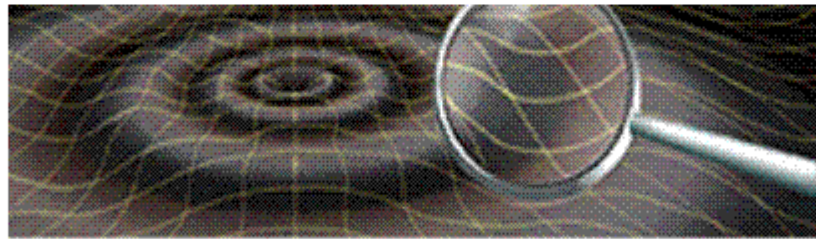
Stronger gravity → more of a redshift

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

Perihelion Advance of Mercury
(show animation)



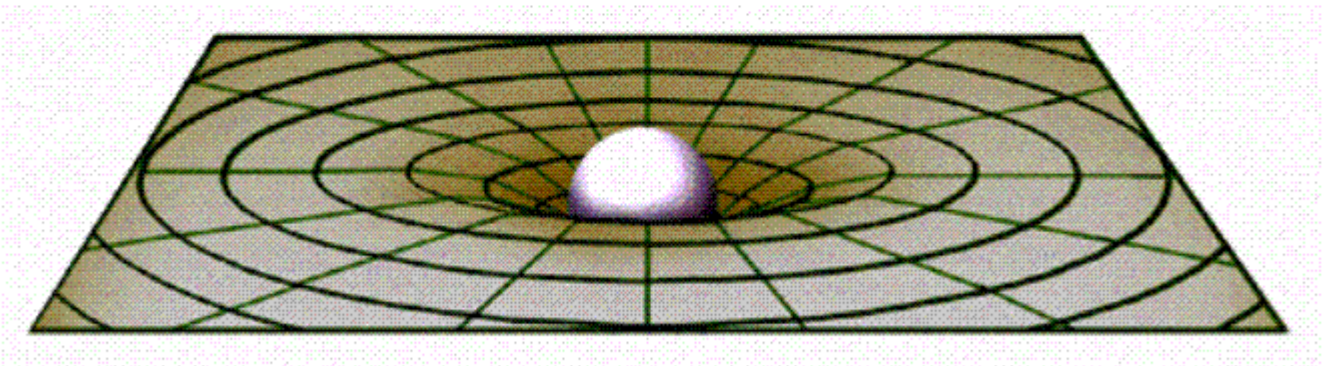
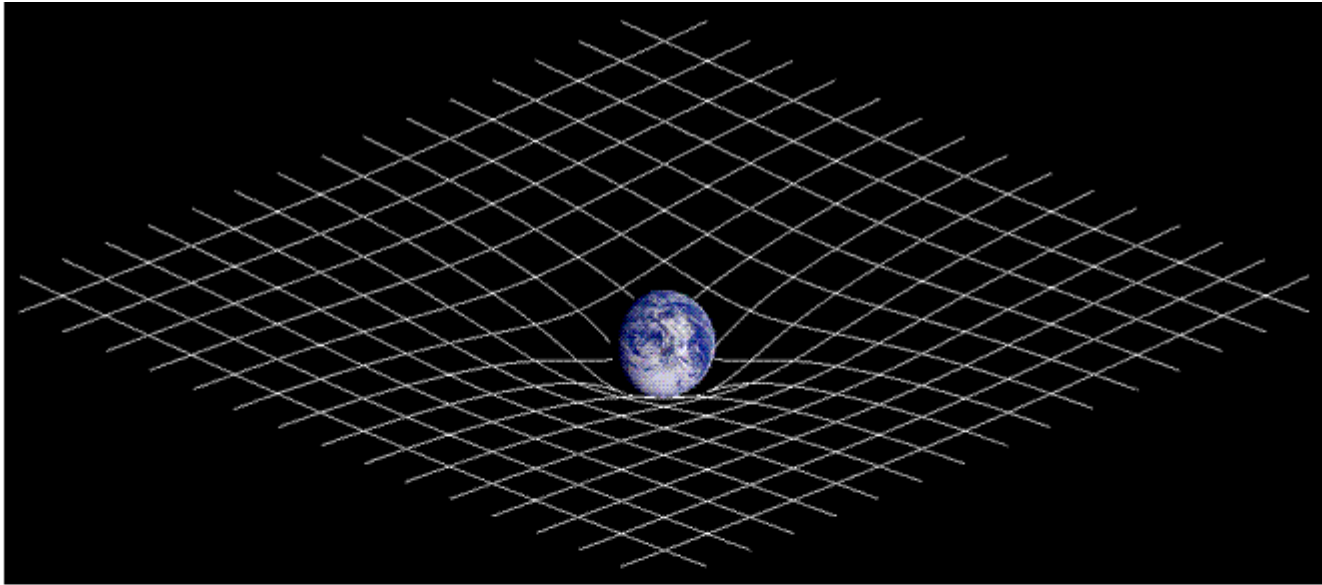
G.R. predicts existence of waves traveling in the fabric of spacetime \rightarrow gravitational waves



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



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

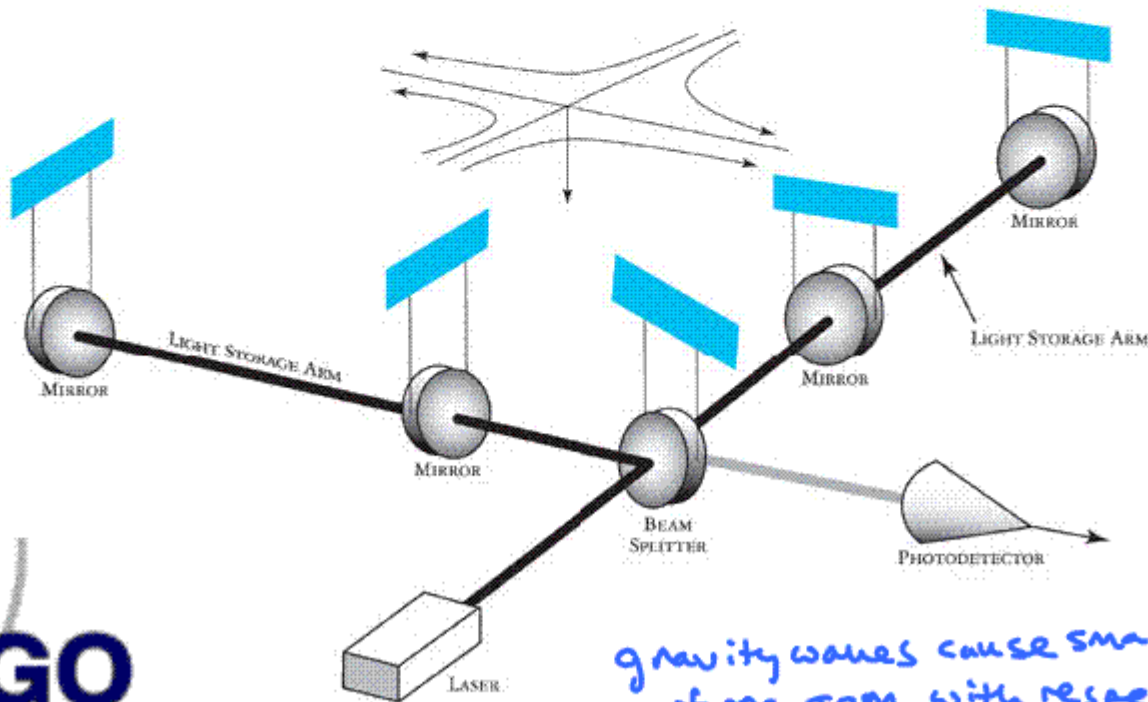
LIGO - Laser Interferometer Gravitational Wave Observatory

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

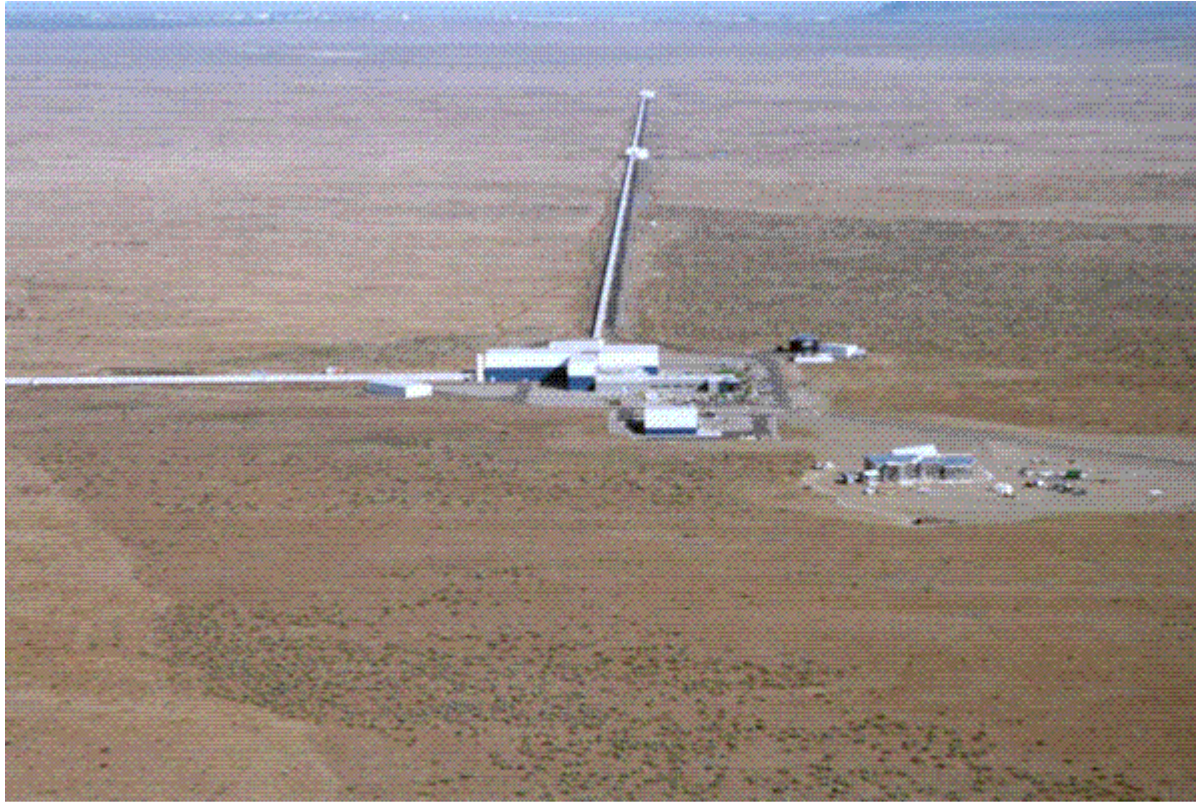


Distortions
 $\sim 10^{-16}$ m

Arms
 ~ 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

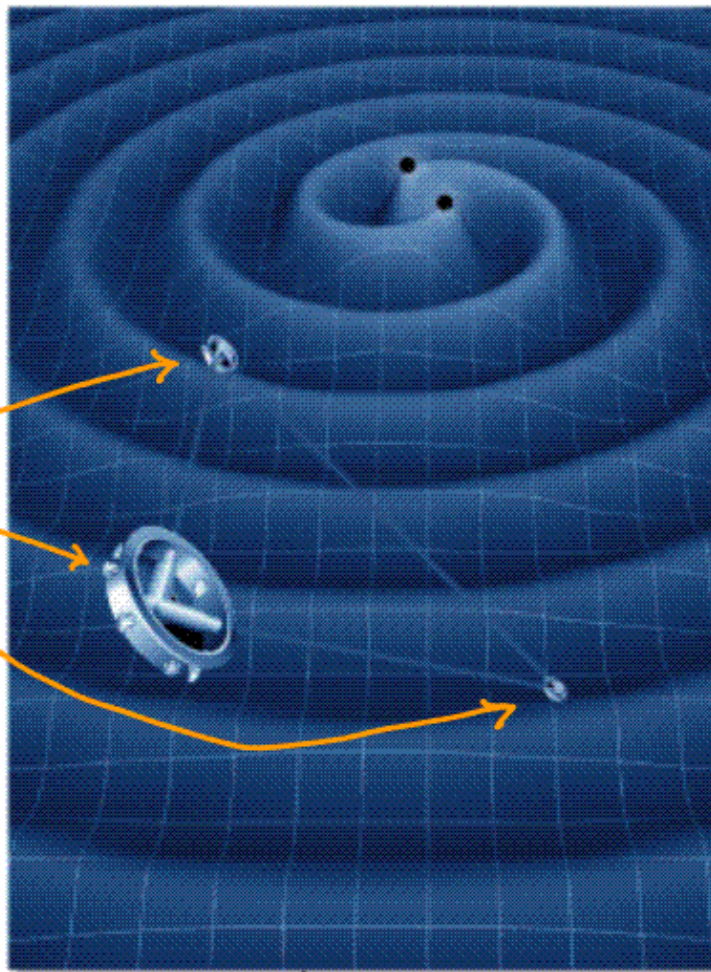


There are other projects ...

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