## Physics 514 General Relativity
## Prof. Alex Maloney
## McGill University

**http://www.physics.mcgill.ca/~maloney/514/**

**Lecture 1**
**The lecture starts 38 minutes into the recording**

## Physics 237 Gravitational Waves
## Prof. Kip thorne
## Caltech

**http://elmer.tapir.caltech.edu/ph237/**
**http://elmer.tapir.caltech.edu/ph237/week2/week2.html**

**Lecture 3 Tape 2**
**We started 13 minutes into the recording**

**Lecture 4 Tape 1**
**We started at the beginning of the recording**

# Introduction

GR is the theory of classical gravity.

**Basic Idea:** Forces are described by fields

e.g. ① Newtonian GR field $\Phi$

② EM $\vec{E}$ & $\vec{B}$

A field theory has 2 parts ...

① EOM which determine the field in terms of sources. "Field eqn"

① $\nabla^2 \Phi = (4\pi G)\rho$ ← mass density

② $\vec{\nabla}\cdot\vec{E} = \rho$ ... etc.

② Force law: determines the motion of objects in the presence of the field!

① $\vec{F} = m\vec{a} = m\vec{\nabla}\Phi$

② $= q(\vec{E} + \vec{v} \times \vec{B})$

So far we have taken the fields to be functions of $(t, \vec{x})$ i.e. $\phi = \phi(t, \vec{x})$

$$\vec{E} = \vec{E}(t, \vec{x})$$

The force law tells us how motion will differ from a straight line in the field,

$$\vec{a} = 0 \Rightarrow \text{line.}$$

<u>GR</u>: Gravity is not due to a field which is a function of $t, \vec{x}$ but rather to a feature of ST itself.

$\Phi \rightarrow$ A "metric tensor" $g_{\mu\nu}$ which describes curvature of ST

The field eqn determine the curvature of ST in terms of sources

$$\boxed{R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} = 8\pi G\, T_{\mu\nu}}$$

"Einstein Eqn"

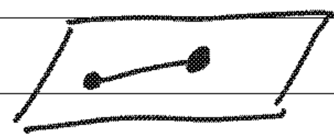
$$\nabla^2 \phi = 4\pi G \rho$$

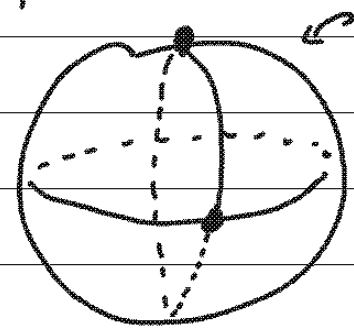
The Force law is the geodesic eqn.

$$\boxed{\ddot{x}^{\mu} + \Gamma^{\mu}_{\nu\rho}\,\dot{x}^{\nu}\dot{x}^{\rho} = 0}$$

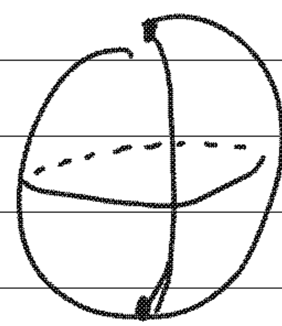
describes how objects move when ST is curved.

Objects travel ~~in~~ on "straight lines" in curved ST.





This notion completely characterizes classical gravity.



# SpaceTime

Space-time is the set of all $(t, \vec{x})$

A "point" in spacetime is an "event"

ST is a set of "events" which can be parametrized by e.g. cartesian or polar coords. in a smooth way.

$$(t, \vec{x}) \quad \text{or} \quad (t, r, \theta, \phi)$$

General Covariance: physics should be indep. of the choice of coord. system.

In newtonian physics, for two events $(t_1, \vec{x}_1)$ & $(t_2, \vec{x}_2)$

$$\Delta t = t_2 - t_1$$

$$\Delta x = \sqrt{(\vec{x}_2 - \vec{x}_1) \cdot (\vec{x}_2 - \vec{x}_1)}$$

The two quantities $\Delta t$ & $\Delta x$ make sense in newtonian physics.

In SR. ~~the~~ $\Delta t$ & $\Delta x$ do not make sense independently. There is no indep. notion of the time separation or spatial separation bet. 2 events...

These notions depend on which ref. frame we use.

In SR. there is one notion which does make sense indep.

"Invariant Interval" $\Delta s$

$$\Delta s^2 = -c^2 \Delta t^2 + \Delta x^2$$

$$= -\Delta t^2 + \Delta x^2$$

We use units $c = 3 \times 10^8$ m/s

$= 1$ light seconds/second

<u>Claim</u>: All of SR. is just the statement that for two events $(t_1, \vec{x}_1)$ & $(t_2, \vec{x}_2)$, the time measured by an observer moving at const. velocity between those events

is $(\Delta \tau)^2 = -(\Delta s)^2$