Course Logistics

Lecture 1

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Everything on course websites:
http://bohr.physics.berkeley.edu/hal/teaching/phys139

bspace site

- Come to Lecture!
- Come to sections!
- Ask questions
- Names
- Debt to David Griffiths

Homework: Due Tuesdays at 5pm in 251 LeConte

Office Hours:

proposal –

Hal Fri: 4-5pm, Tues 3:30-4:30

Eugene Mon two hours

Today's Outline:

I What is G.R.?

II Logistical Interlude

III Principal of Equivalence

IV A little geometry

I. What is GR?

(a) Generalized Special Relativity

(Ok to work in <u>any</u> reference frame even acc.) (ok to use any ref. frame moving at consistant velocity)

(b) Einstein's theory of gravity

(i) Newtonian Gravity $m_1 \xrightarrow{\vec{r}} m_2$

Universal gravitation: $\vec{F} = -\frac{G m_1 m_2}{r^2}\hat{r}$

Second law: $\vec{F} = m\vec{a}$

$$\Rightarrow \quad m_2 \vec{a} = -G \frac{m_1 m_2}{r^2} \hat{r}$$

But it's inconsistent with special Rel. Contrast E & M — already relativistic.

Why not modify gravity just as we did with Coulomb's law,

$$\vec{F} = \frac{1}{4\pi\epsilon_0} \frac{qQ}{r^2} \hat{r} \ ?$$

$$\longrightarrow \rho, \vec{J} \Rightarrow J^\mu = (c\rho, \vec{J})$$

$\vec{E}$ & $\vec{B}$ form a tensor —

$$F^{\mu\nu} = \begin{pmatrix} 0 & E_x/c & E_y/c & E_z/c \\ -E_x/c & 0 & B_z & -B_y \\ -E_y/c & -B_z & 0 & B_x \\ -E_z/c & B_y & -B_x & 0 \end{pmatrix}$$

Maxwell's Eqns: $\frac{\partial F^{\mu\nu}}{\partial x^\nu} = \mu_0 J^\mu$

This doesn't work!

Here's why:

Inspiration: do for the law of Univ. gravitation what Maxwell, Ampere, Faraday did for Coulomb's law (e.g. $q \rightarrow m$). [Doesn't work].

Sources of E & M fields: electric charge & current

Why not substitute $q(\rho_e) \rightarrow m(\rho_m)$? Because mass, unlike charge, is not additive — total mass of composite structure reflects all forms of energy contained (kinetic, potential, & rest) via $E = mc^2$.

Maybe all forms of energy are sources of gravity.

O.K. But energy is not a Lorentz scalar – it's one component of the energy-momentum 4-vector:

$$P^{\mu} = \left(E/c, \vec{p}\right)$$

So momentum <u>also</u> will be a source of gravity. Moreover what we need is energy-momentum <u>density</u> – they fit together

So we're looking for an equation of the form:

$$\boxed{???} = (G)\,T^{\mu\nu} \leftarrow \text{source}$$

It took Einstein 12 years to find "?"s.

to make the stress-tensor (or energy-momentum-stress tensor)

$$T^{\mu\nu} = \begin{pmatrix} \boxed{\text{En. dens.}} & \boxed{\text{Momentum density}} \\ \boxed{} & \boxed{\text{Pressure, etc.}} \end{pmatrix}$$

Done with analogy ~~with~~ between E & M and Gravity.

II Logistical Interlude

(i) Schedule 2nd section

(ii) Schedule office hours

(iii) Vote on course Tracks

Three tracks:

Track 1 (T1) Gravitational Waves

Track 2 (T2) Black Holes

Track 3 (T3) Cosmology

ii) How many can't make scheduled discussion (Th 4-5pm)?

What's the conflict?

2nd Disc. Sec times: 11-12pm

<u>Day</u> <u>Time</u> <u>Votes</u> ~~Monday~~. ~~Wednesday~~. Monday

OH proposal:

<u>Day</u> <u>Time</u> <u>Votes</u>

Hal Fri 4-5pm Tues 3:30-4:30pm

Eugene: Mon 2:30-4:30

On sheet Rank tracks in order of preference

e.g. 1) T1
2) T3
3) T2

- Mention structure of book here.

Computers & Mathematica

DSP

Grade: HW 55%, MT 15%
Final 30%

Comments? Other logistics?

III Principle of Equivalence

Recall Newton: $\cancel{m}\vec{a} = -G\frac{\cancel{m}M}{r^2}\hat{r}$

Mass plays two <u>unrelated</u> roles — on the left inertia (i.e. a measure of $|\vec{F}|/|\vec{a}|$), and on the right the strength of gravity — and cancels out.

Therefore all objects fall under gravity w/ same acceleration.

$$\boxed{\text{inertial mass} = \text{grav. mass}}$$

Gravitation is Geometry

Einstein: gravity is not a force at all, but a feature of ~~spacetime~~ space/time.

Then, matter (stress-energy) curves space/time — particles (test) move on geodesics in this curved spacetime (generalizing N's 1st law).

IV A little geometry

Different geometries have different properties, e.g.:

$$\sum_{\substack{\text{vertices}\\ \text{in triangle}}} \left(\begin{matrix}\text{int.}\\ \text{angle}\end{matrix}\right) = \pi$$

for Euc. plane

$$\sum_{\substack{\text{vertices}\\ \text{in tri.}}} \left(\begin{matrix}\text{int.}\\ \text{angle}\end{matrix}\right) = \pi + \frac{\text{Area}}{a^2}$$

on Sphere of radius a

Returning to

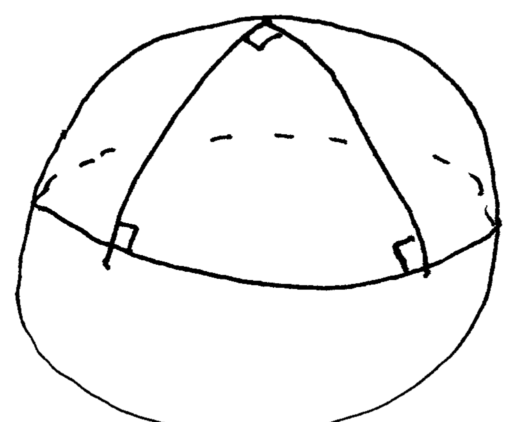
$$\boxed{???} = (G)\, T^{\mu\nu}$$

some measure of curvature

Theory of curvature:

Gauss → Riemann

Differential Geometry



Lobachevsky, Bolyai and Gauss realized that these were meaningful outside of Eucl. Geom