0. INTRODUCTION TO GENERAL RELATIVITY

[MTW signs]

Special relativity (Einstein 1905) (SR)
General relativity (Einstein 1915) (GR)
(theory of)

- Special relativity applies to all physics, except gravity

  in particular: - Electrodynamics is consistent with special relativity, and played an important role in its development.
  - Newtonian gravity is not consistent with special relativity

  ⇒ Einstein developed general relativity

- General relativity = new theory of gravity, which replaces Newtonian gravity
- GR is a generalization of SR, i.e., it includes SR as a special case

- Central idea: Space and time are combined into a 4-dimensional spacetime

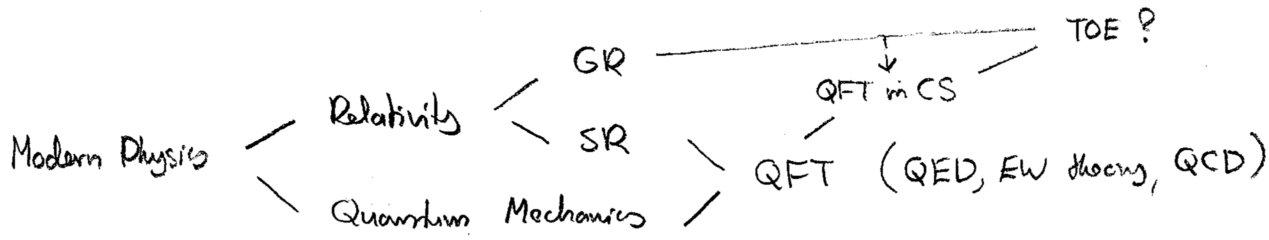
  SR: spacetime is flat (= not curved) "Minkowski space"

  GR: spacetime is curved (manifestation of gravity)

- A misconception seen sometimes in literature, is that "SR cannot handle accelerating motion, for that GR is needed". Not true!
  SR can handle acceleration perfectly well. Constant (nonaccelerating) motion, and related <u>inertial frames</u> just have a special role in SR: physics looks particularly simple when discussed using an inertial frame. Thus the equations of SR are ordinarily written in inertial frames. In GR, equations are written in arbitrary frames (coordinate systems)

SR and GR do not include quantum physics

SR and quantum mechanics have been succesfully combined in Quantum Field Theory; but theorists are still looking for the right way to combine GR and quantum physics into a "Theory Of Everything" (TOE) (String Theory is a candidate).



- QFT has been succesfully "half-combined" with GR as "Quantum Field Theory in Curved Spacetime", where other fields are quantized and evolve in a curved spacetime which is a solution of GR, but gravity itself remains classical (is not quantized). Important predictions of QFT in CS are 1) Hawking radiation from black holes, and 2) generation of primordial density perturbations from quantum fluctuations during inflation (cosmology).

- Linearized gravity: For weak gravitational fields, which can be considered as small perturbations around Minkowski space, one can make an approximation (first order in perturbation) to GR, where the equations of GR become linear (Chapter 7 of this course and Carroll's book). This linearized gravity can be succesfully quantized. Those gravitational field quanta are called gravitons.

- This course does NOT cover quantized linear gravity or QFT in curved spacetime. Chapter 9 of Carroll's book does give an introduction to the latter.

Newtonian Gravity vs GR:

Newtonian gravity

$$\vec{F} = -G\frac{Mm}{r^2}\hat{r}$$

$$\vec{F} = m\vec{a}$$

or

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

$$\vec{a} = -\nabla\phi$$

GR

Gravity is not a force

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} = 8\pi G T_{\mu\nu}$$

$$\frac{d^2x^\mu}{d\lambda^2} + \Gamma^\mu_{\rho\sigma}\frac{dx^\rho}{d\lambda}\frac{dx^\sigma}{d\lambda} = 0 \quad \text{for } x^\mu(\lambda)$$

Gravity is Geometry

Pythagoras $(\Delta L)^2 = (\Delta x)^2 + (\Delta y)^2$ Euclidean geometry (space is flat)

Metric tensor $g_{\mu\nu}$: geometry of spacetime

$$(\Delta L)^2 \neq (\Delta x)^2 + (\Delta y)^2 \quad \text{in general}$$

"Matter tells spacetime how to curve, spacetime tells matter how to move." [MTW]