Why I like General Relativity (GR):
- GR is one of the few "hard core" subjects that students are into in the game (after they have a pretty solid understanding of basic physics).
- GR raises/addresses some of the BIG questions in physics, e.g. cosmology, nature of spacetime.
- GR is one of the most perplexing issues confronting theoretical physics, i.e. Quantum Gravity.

What is "general" about GR and how is it related to Special Relativity (SR)?
Many people think that GR is a generalization of SR... and they are wrong! (But really, who could blame them?!!)

To answer this we will first consider familiar correspondence principles (general → limited).

\[
\text{Newtonian Mechanics} \quad \text{(particle+fields)} \quad \text{(most limited case)} \quad \text{slow speeds compared to } c
\]

\[
\text{NR Quantum Mechanics} \quad \text{(particle+fields)}
\]

But: QM is true for large systems.

By the discreteness is relatively small.

e.g. SiO \quad E = (\hbar/2\pi) k \omega

\[ E = \hbar \omega \text{A} \]

\[ n(h\hbar, \omega = 1/2, A = 1) \quad (\hbar^2 = 0) \]

Statistical: Classical behavior arises for any particle due to lack of molecular coherence (exceptions are cardinals).

Path integral:

Path weighted by \[ e^{iS} \] \text{S} \tiny{\text{(classical)}}, \quad \text{so that } g \ll \text{S} = \text{S}_{\text{classical}}

rapid fluctuations cancel except for extreme \& \text{S}\text{tiffle}, i.e. classical motion.

\[ V < c < \]

\[
\text{Quantum Field Theory} \quad \text{(no more particles, only fields)} \quad \text{Why? a field theory?}
\]

QM for particles requires non-trivial normalization to conserve particle number.
SR for particles allows creation/annihilation or changing particle number.

We could combine them with fields, but it is ugly and doesn't incorporate effects that we know happen, e.g. Higgs mechanism.
Okay, so where does GR fit in? All of the above (NM, GA, SR, QFT) are frameworks for mechanics. By themselves, they do not constitute theories. To have a theory, you need a framework plus degrees of freedom and their interactions.

Punkin: GR is a theory, not a framework. It is a theory of the gravitational interaction. Two conclusions:
1) There is no correspondence principle relating GR to SR.
2) GR is actually a generalization of Newtonian gravity (valid when \( \frac{c}{R} \gg \alpha \)).

Okay, but you still might ask how GR and SR are related. The answer is that SR is one particular solution of GR, i.e., a flat spacetime with no gravity acting.
In going beyond Newtonian gravity to GR we are going to be faced with a lot of new ideas, e.g., manifolds, curvature, tensors, etc.

Before it gets hairy though, we can paraphrase GR by analogy with another theory you know well, **Electrodynamics**:

\[
\begin{align*}
\mathbf{E} &= \nabla \Phi \\
\mathbf{B} &= \nabla \times \mathbf{E} \\
\mathbf{B} &= \frac{\partial \mathbf{E}}{\partial t} + \frac{\partial \mathbf{B}}{\partial t} \\
\mathbf{F}_{\text{em}} &= q(\mathbf{E} + \mathbf{v} \times \mathbf{B}) \\
\mathbf{F}_q &= m \mathbf{a}
\end{align*}
\]

**Maxwell’s Equations** \( \Rightarrow \) Tell us how sources \((A, \phi)\) create fields \((E, B)\) (w/ some topological constraints)

This is an example of a background-free particle split which though not fundamental, is still very useful for computation and application!

General Relativity:

**Einstein’s Equation** \( \Rightarrow \) Tells us how sources create gravitational fields/curvature.

**Geodesic Equation** \( \Rightarrow \) Tells us how a test particle responds to curvature.

So how have a gravitational field? Actually no, not in the Newtonian sense. However, in describing the curvature of a spacetime we will need to introduce perhaps the single most important element of GR, the metric field.