Lecture 1: What is space?

Note Title 1/18/2011

What is space?

2 very different answers

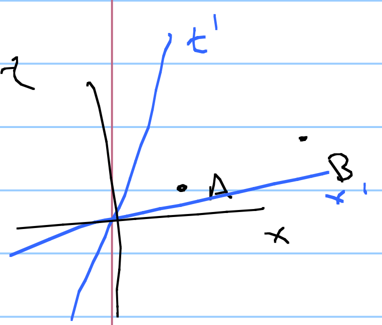
(1) Space is an entity by itself (Newton)
(2) Space is relational (between objects) (Leibnitz, Descartes)

There is a long history in thinking about this question. (See Lecture 1 Supplement)

Newton's success allowed his entity view to become dominant.

This turned out to be a mistake.

- In special relativity, different observers will see two events as having different spatial separations. If space is an entity, how can there be more or less of it between the same two events viewed by different observers?



2 observer diagram of special relativity

- In cosmology, we know the universe is "expanding." All distant galaxies are receeding from us according to Hubble's Law

unfortunate word choice

$$V = H_0 d \qquad H_0 = 72 \pm 7 \ \frac{km/s}{Mpc}$$

But those galaxies are locally stationary. Is space being created between us?

General Relativity asks us to make a conceptual shift in how we approach gravity.

↳ Gravity is geometry: A dynamical interplay between matter + geometry at its heart.

↳ Gravity is a false force - the person who feels it is in an un-natural state of motion.

↳ The relations and Laws of GR arise when considering the motions of observers. They arise when thinking in a relational viewpoint.

↳ For all this to work, a special kind of mathematics must be employed: General Co-variance

Stepping away from GR...

Our basic theoretical outlook has two components

(1) Quantum Mechanics – or Quantum Field Theory (QFT)

(2) Gravity (as described by general relativity)

⟹ The standard model for QFT describes electromagnetism, the "weak interactions" and the "strong interactions" with the group structure:

Take a moment to look at figure on page 5, eqn 1.6

Standard Model ⟺ $SU(3) \times SU(2) \times U(1)$

A key goal of physics is to combine QFT w/ Gravity

→ To find a theory of <u>Quantum Gravity</u>.

No approach has solved this problem. Major attempts include

- strings, supersymmetry, etc
- loop QG, canonical QG, spin foams, etc
- Euclidean Gravity (Hawking)
- twistors (Penrose)

Over the past 30 years, the "excitement" of being close to a solution has come and gone 2 or 3 times.

We are currently in a prolonged "excited" phase.

Some recent developments highlighting how little we know.

- The LHC hopes to find the Higgs Boson — very important to standard model + supersymmetry + strings, etc.

→ LHC operates at $14\,TeV = 1.4 \times 10^{13}\,eV$

→ $E_{pl} = \left(\frac{\hbar c^5}{G}\right)^{1/2} = 1.22 \times 10^{19}\,GeV = 1.22 \times 10^{21}\,eV$

There is a hell of a lot of energy difference here. Is it one turtle, or are there turtles "all the way down"?

- We now know that baryons account for only 4% of the energy density of the universe.

$\Omega_m \simeq .3$, $\Omega_\Lambda \simeq .7$ (Dark energy)

$\Omega_{baryons} = .04$ $\Omega_{DM} = .26$! (Dark matter)

↑ Haven't detected directly, probably complicated

→ The Dark Energy could be simple – cosmological constant – or complicated.

- Either way, why is there so much of it?

- Review course direction
- Assign HW 1, reading assignment is chapter 1 both for Monday