The new invariants

World lines

4-dimensional physics

Causality

The twin "paradox"

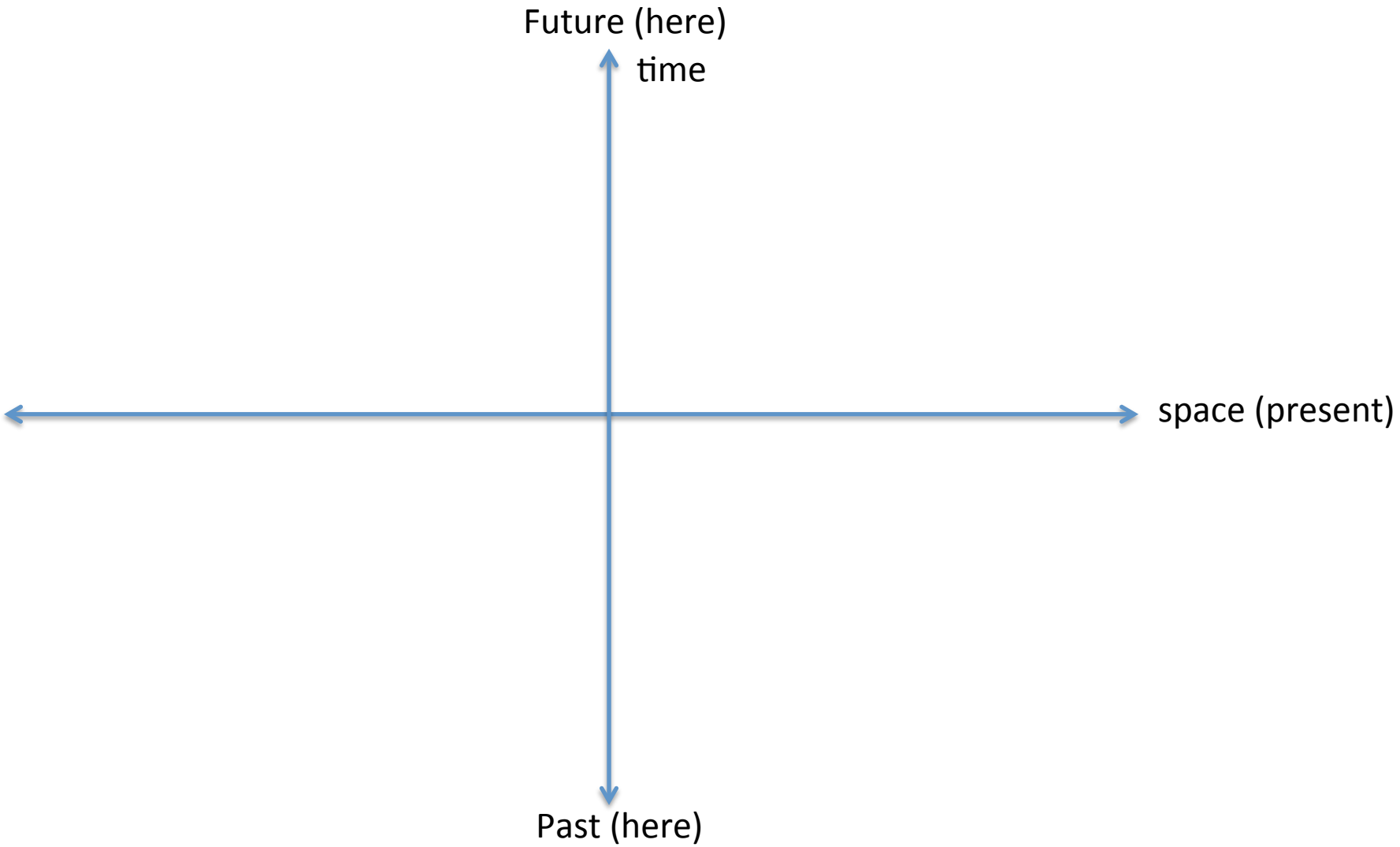
Next:

Accelerated reference frames and general relativity

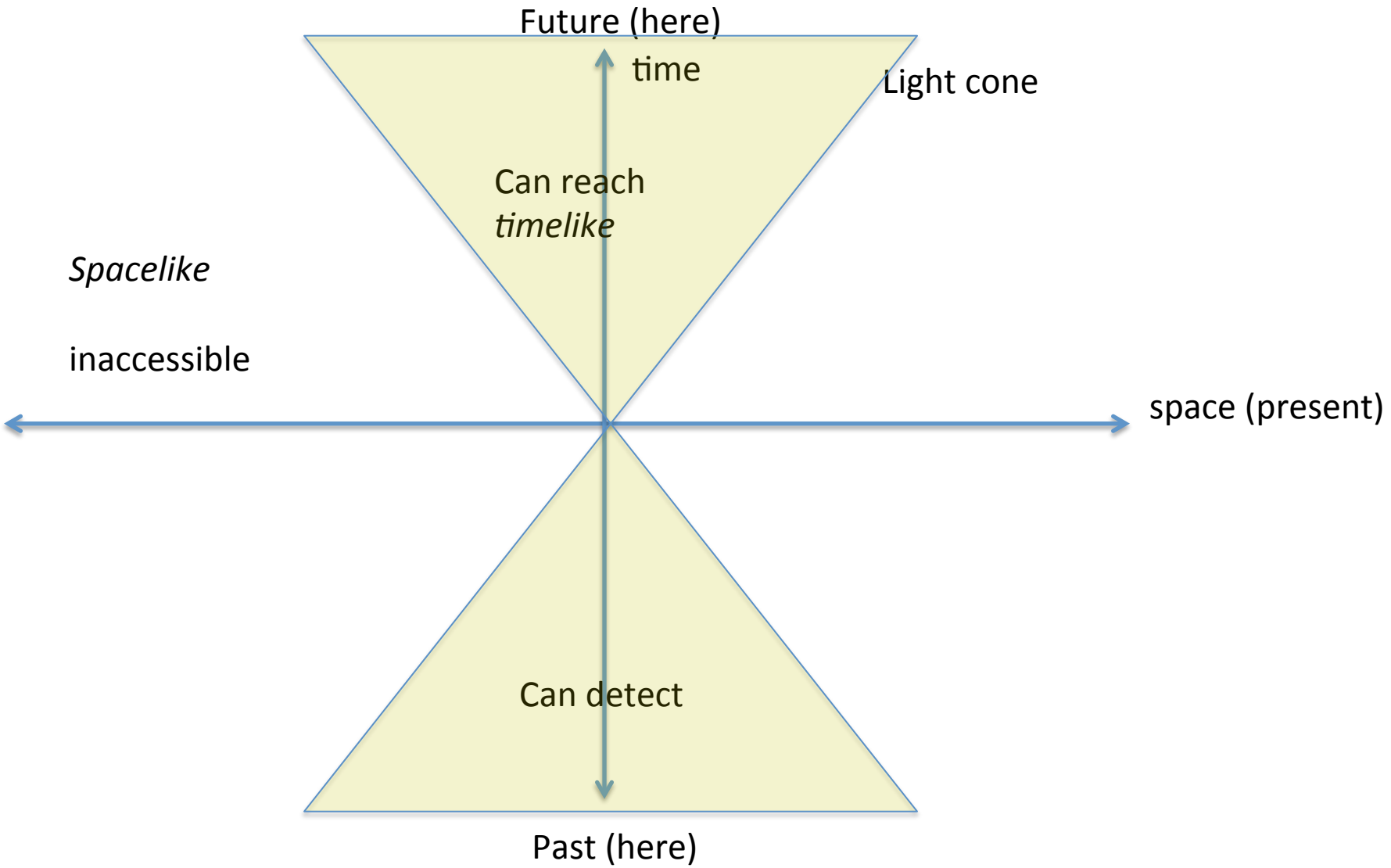
Term paper topic due March 17

HW4 due on Thursday

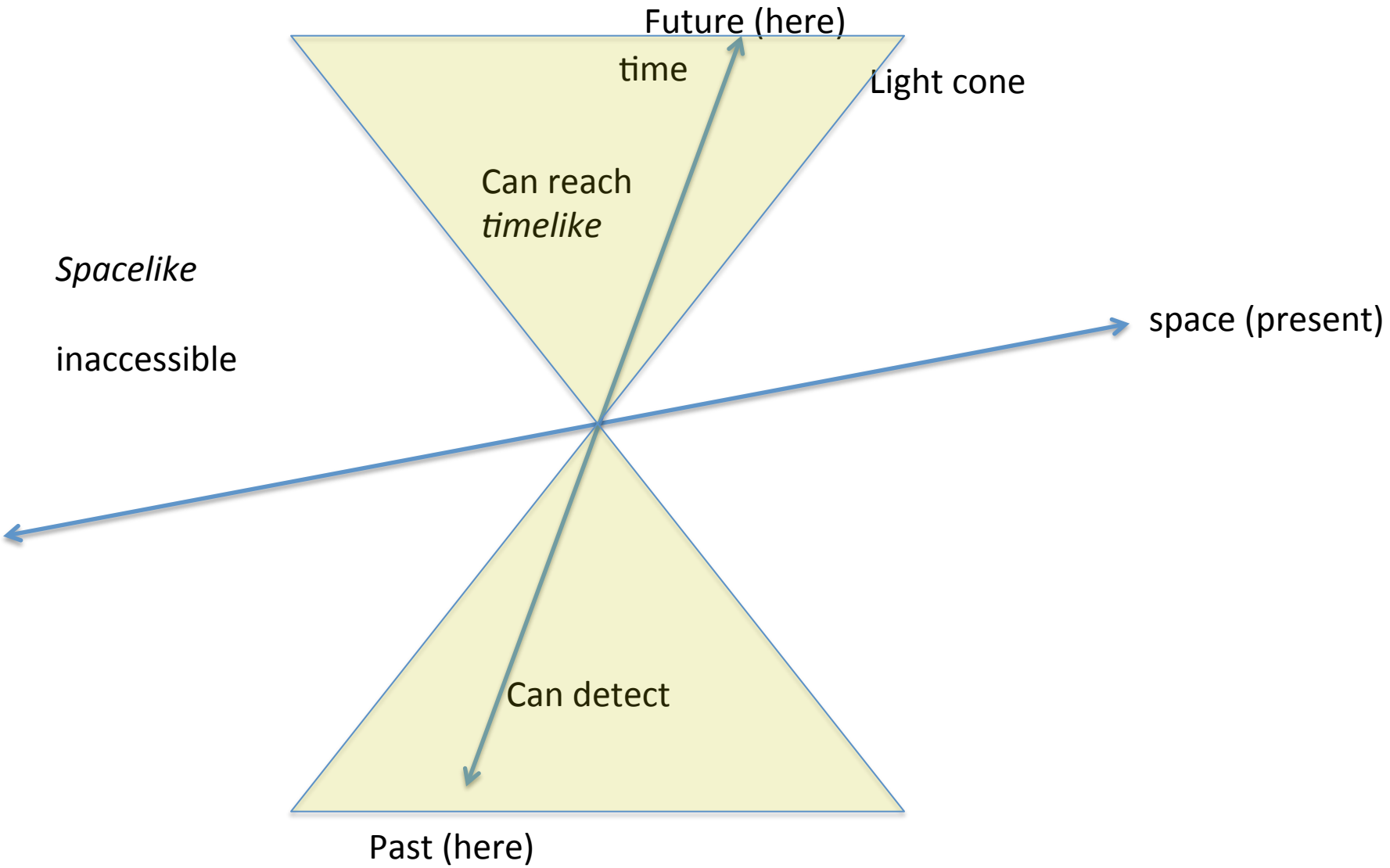
Space-time diagrams



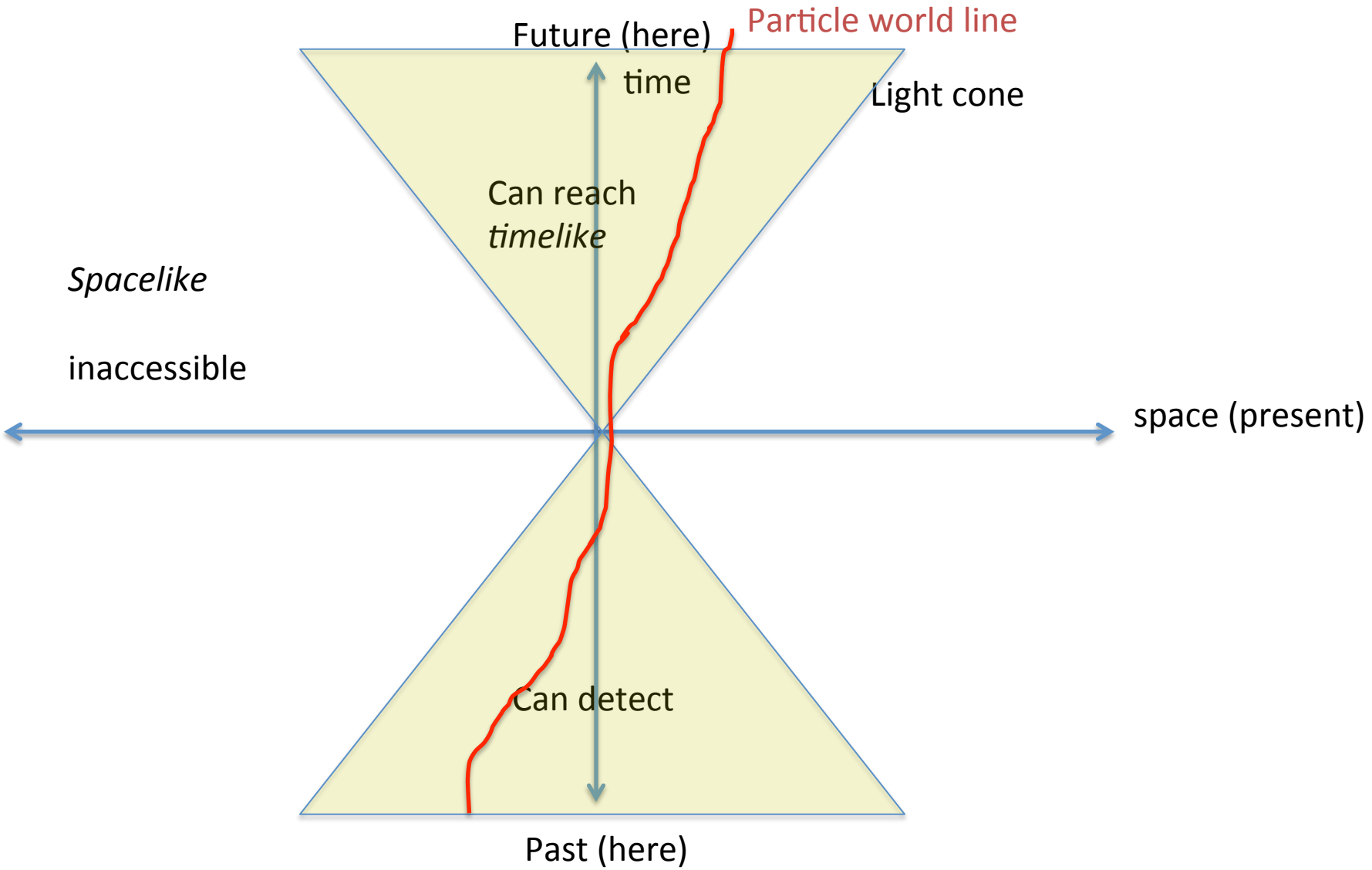
Space-time diagrams



Spacetime from rocket



Space-time diagrams



What does “Nothing can travel faster than the speed of light” mean?

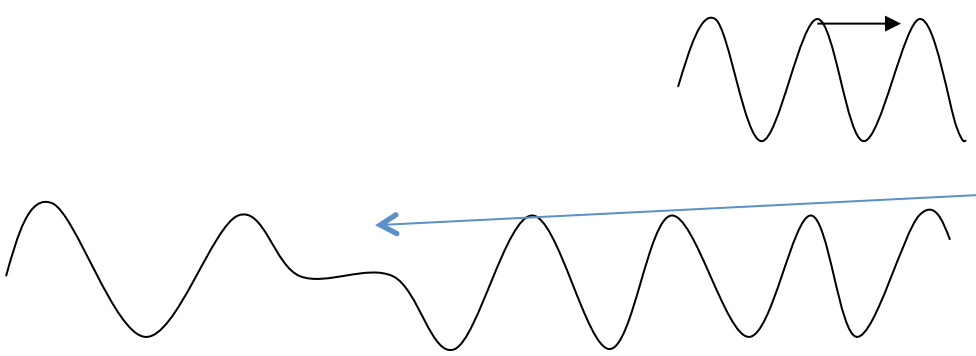
We know that

- no ordinary mass can go faster, because that would require infinite energy.
- no conserved quantity can go faster, because then it would not be conserved in some reference frames.
- If we believe that causation must go forward in time, then we know that no "information" can go faster than c, because that would allow backwards-in-time causation.
  - What happens if you can send info backward? Say you send your grandma info that somebody much cuter than your grandpa was about to move into her neighborhood. Then you aren't born. Then the info doesn't get sent. So you are born, so …….

What does "no object travels faster than c“ mean?

If "no object travels faster than c", then the following aren't objects:

- The bright spot made by a beacon shining on a wall.
- The cutting point of a scissors.
- The crest of an E-M wave in matter. (Certain materials have index of refraction less than 1 over some frequency range, hence a "phase velocity" greater than c for some light.)



The repetitive pattern carries no info!

Only the *breaks* in the repeating pattern must travel slower than c.

What are we then claiming?

If we are to describe the world as having some primary constituents, with various higher-level phenomena just being patterns in the constituents' behavior, we want to restrict the primary constituents to those which don't travel faster than light. We claim there exists *some* complete description of the world in terms of constituents which don't travel faster than c.

Causality in Special relativity

- Things:
  - One version of positivism tried to reduce all statements to simple relations among "things".
  - You are all familiar with statements such as "No two things can be in the same place at the same time."
  - We see statements like "No thing can travel faster than the speed of light."
- So what is a “thing”?
  - Is the Mississippi river a thing? (What would Heraclitus have said?)
  - Is a person a thing?
  - Is a moving bright spot on the wall a thing?
- If you believe in external reality, is it necessary to believe it consists of well-defined things?
  - If not, what becomes of statements like those above?
  - Do things exist outside our description of events?

What has SR changed philosophically?

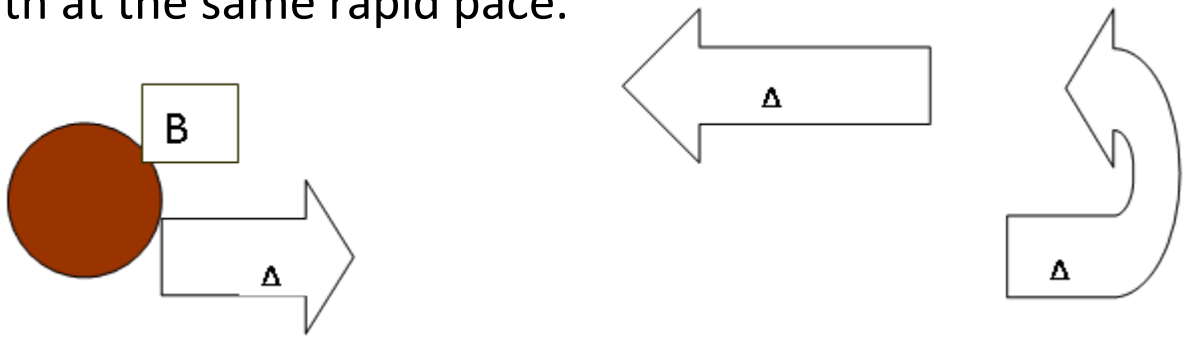
- The old invariants (t, lengths, m …) (things which were "real" in that they were observer-independent) have been tossed out. They are replaced with new invariants (c, d^2-c^2t^2, E^2-c^2p^2…) which have a slightly more complicated relation to our customary observations.

- If we had evolved experiencing many relative speeds close to c, there would be absolutely nothing philosophically exotic or particularly "relativistic" about "relativity". The Lorentz transformations would make sense to us in the same way that the Galilean transformations make sense. We would just have a different set of invariants.
  That's why Einstein wanted to name the theory "Invariants theory."

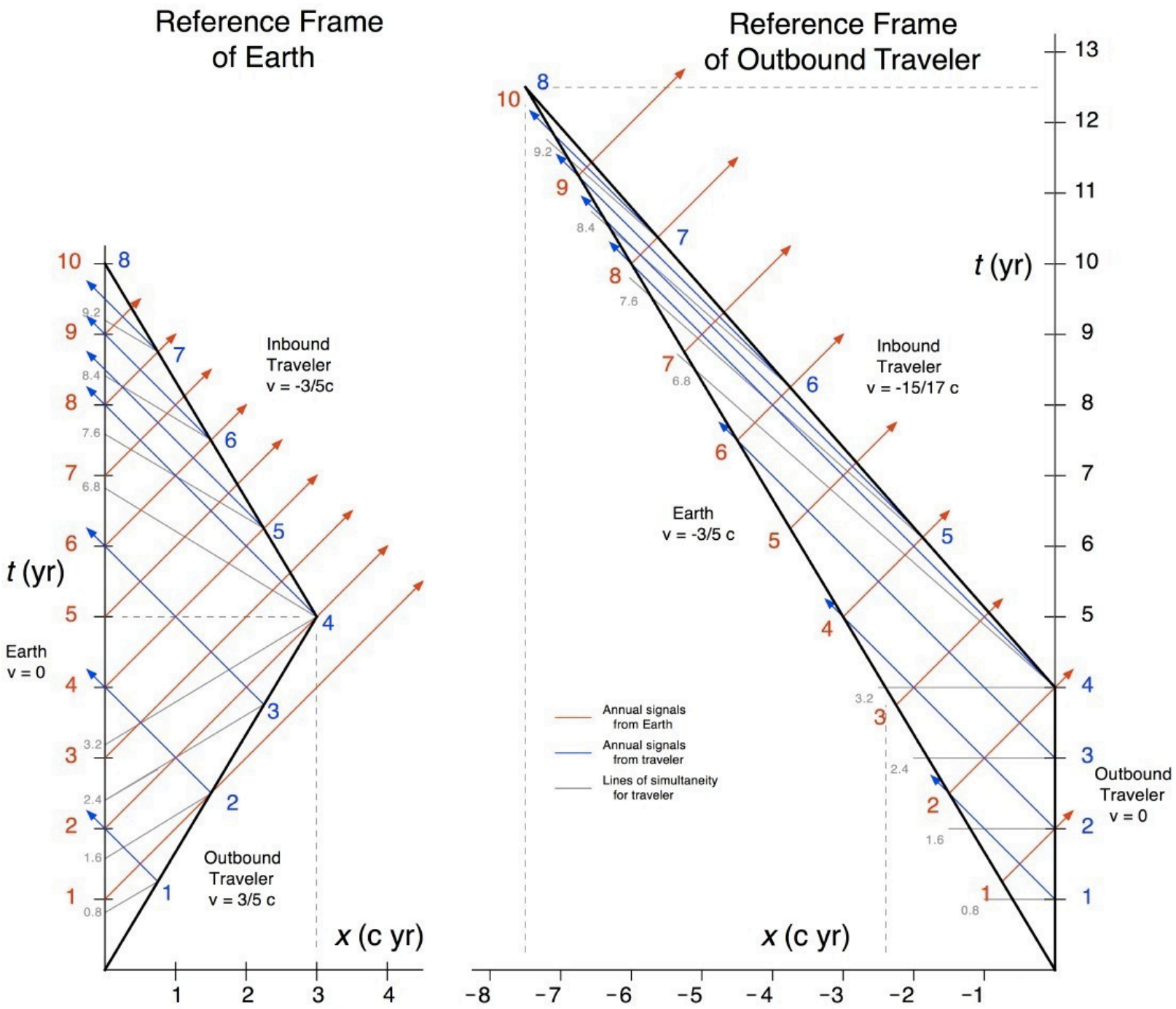
- The philosophical excitement comes from the transformation from one theory to the other- ideas that seemed immutable turned out to be mutable, and there's a lesson to be learned from that process.

The twin paradox

Suppose Alice and Beth are twins. Alice sets off in her rocket so fast that the time dilation factor becomes 10. She travels away from Earth for 10 years, as measured by Beth, who has remained on Earth. Alice then turns around and returns to Earth at the same rapid pace.



When Alice returns home, Beth has aged 20 years. How much has Alice aged?
There <u>appears</u> to be a paradox. According to the Lorentz transformation, during the time Alice is travelling:
<u>Beth says</u>: I measure Alice's clock to be running slow by a factor of ten, so **she** has aged only two years.
<u>Alice says</u>: My clock is fine. I measure Beth's clock to be running slow by a factor of ten, so she has aged only 2 years.
They start and end standing right next to each other, so a direct comparison of clocks is possible. Who is correct?


Reference Frame
of Earth
Reference Frame
of Outbound Traveler
t (yr)
x (c yr)
Earth
v = 0
Inbound
Traveler
v = -3/5c
Outbound
Traveler
v = 3/5 c
Earth
v = -3/5 c
Inbound
Traveler
v = -15/17 c
Outbound
Traveler
v = 0
Annual signals
from Earth
Annual signals
from traveler
Lines of simultaneity
for traveler

Twin Non-Paradox

- The answer is that Alice, the twin who turned around, has aged less.
- The situation is not symmetrical, because in order to return to Earth, Alice must have accelerated. Our descriptions of how things looked to different observers (Lorentz transformations) so far do not describe accelerated observers, so we only know how things look to Beth.
- Of course Alice must agree that Beth is older, when they now stand side-by side. Now we can put together a conclusion about how Beth must have looked to Alice while Alice was accelerating. While turning back (accelerating toward earth), Alice must observe Beth's clock to be running fast, not slow.
- So this is not a paradox at all but just a reminder that the SR transformations only work between reference frames which are not accelerating (*at least* with respect to each other, leaving aside the question of absolute acceleration.) But you can also see that from SR we can draw conclusions about how things *must* look to accelerating observers.
- Let's go further in seeing how things look to accelerating observers. In particular, let's look for ways in which the simple laws of physics might get messed up in their frames.