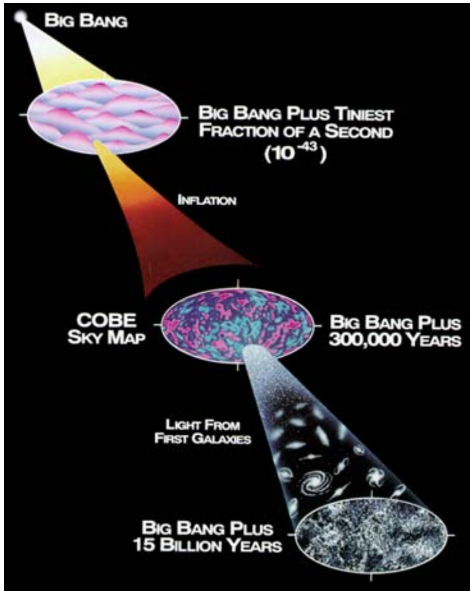
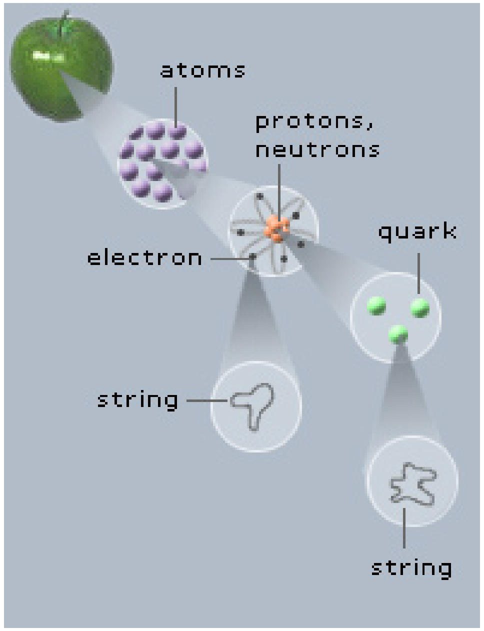
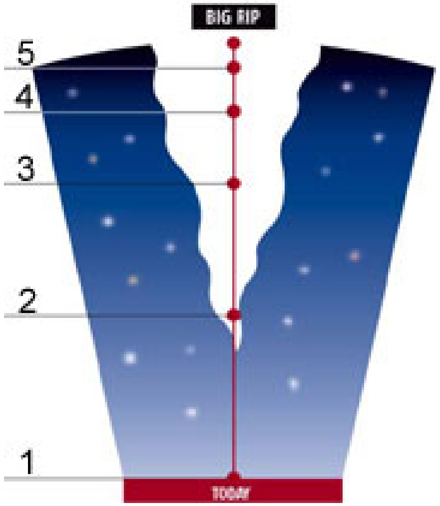
Inflation, 10^{500} vacua and the end of the Universe







Homework

Problems:

1-7 (15 points)

1-10 (25 points)

2-9 (20 points)

2-13 (20 points)

from “Spacetime Physics”

Physics 311
Special Relativity

Lecture 4:
Reference frames.
Lorentz contraction.

OUTLINE

- Formulations of the Principle of Relativity
- Simultaneity, “train paradox” and Lorentz contraction
- Events in the transverse plane

Recall: the principle of Relativity

- “Physics laws are the same in all inertial frames”, or
- “No test of laws of physics provides any way whatsoever to distinguish one inertial frame from another”
- Principle of Relativity is a ***postulate*** – that is, it is not something that has been measured in an experiment, or derived. It has been postulated. Thus, Special Relativity is a *theory*. But a very good one! Tested and verified in numerous experiments.
- A side remark: When Einstein’s paper on Special Relativity came out in 1905, *almost nobody* could understand it! Two years later Minkowski formulated Special Relativity in geometrical terms, making it understandable for all (physicists).

Einstein

- First postulate (principle of relativity)
  - The laws of electrodynamics and optics will be valid for all frames in which the laws of mechanics hold good.
  - Every physical theory should look the same mathematically to every inertial observer.
  - The laws of physics are independent of location space or time.

- Second postulate (invariance of *c*)

  The speed of light in vacuum, commonly denoted *c*, is the same to all inertial observers, is the same in all directions, and does not depend on the velocity of the object emitting the light. When combined with the First Postulate, this Second Postulate is equivalent to stating that light does not require any medium (such as "aether") in which to propagate.

Formulated Special Relativity in geometric terms, invented spacetime diagrams, geometrical representation of the interval, and laid the groundwork for General Relativity, that treats gravity as a geometrical curvature of spacetime

Minkowski

What exactly is the same?

• Physics laws, e.g. Second Law of Thermodynamics, blackbody radiation, Ohm’s Law.

• Fundamental constants: α - the fine structure constant, electron charge

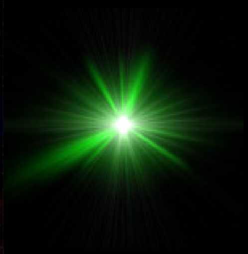
• Speed of light! Consider Alice and Bob:

Bob is flying on the Earth’s orbit in the ISS

Alice is flying by at 99.999% speed of light (Full Impulse)

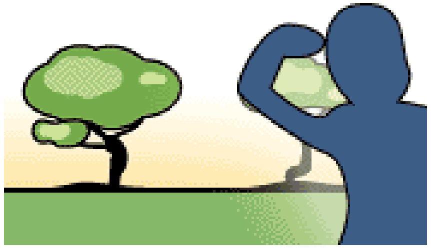
Bob fires a Photon Torpedo parallel to Alice’s line of travel

Speed of light is the same for both!

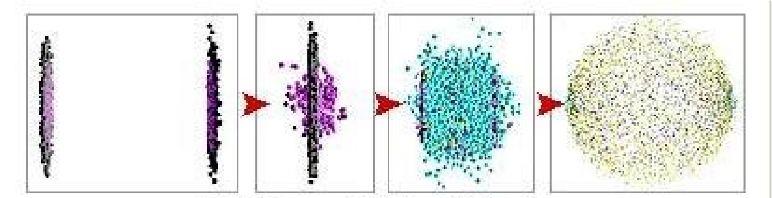


What is NOT the same in different frames?

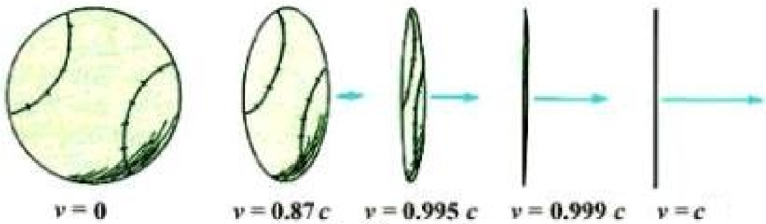
- Space and time separations



- Velocity, acceleration and force



High Energy Collision of Two Ions



Lorentz Contraction

- Electric and magnetic fields

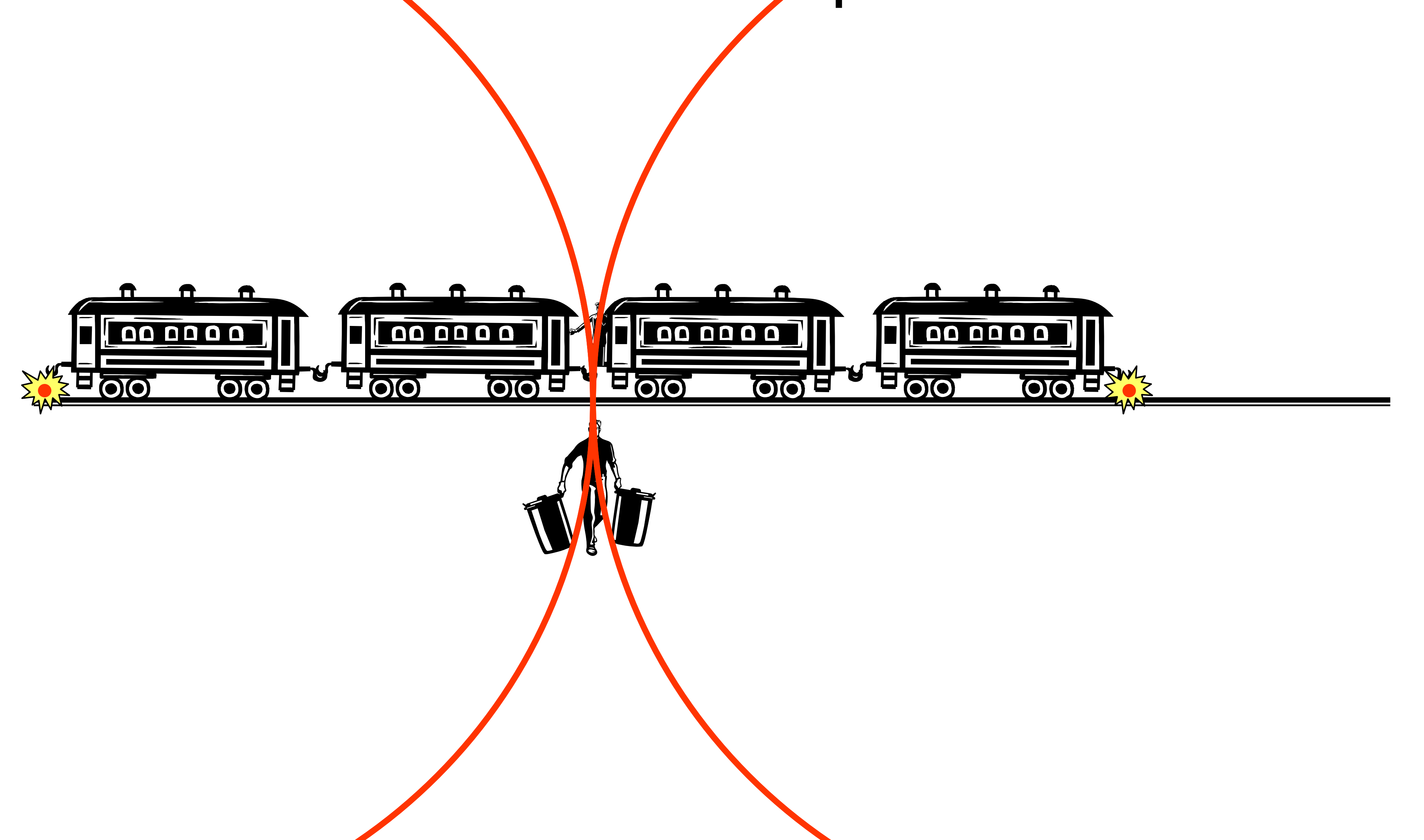
Simultaneity in different frames

- Time separations are *not* the same in different inertial frames. When *are* they *the same* though? When there is no relative motion between the frames.

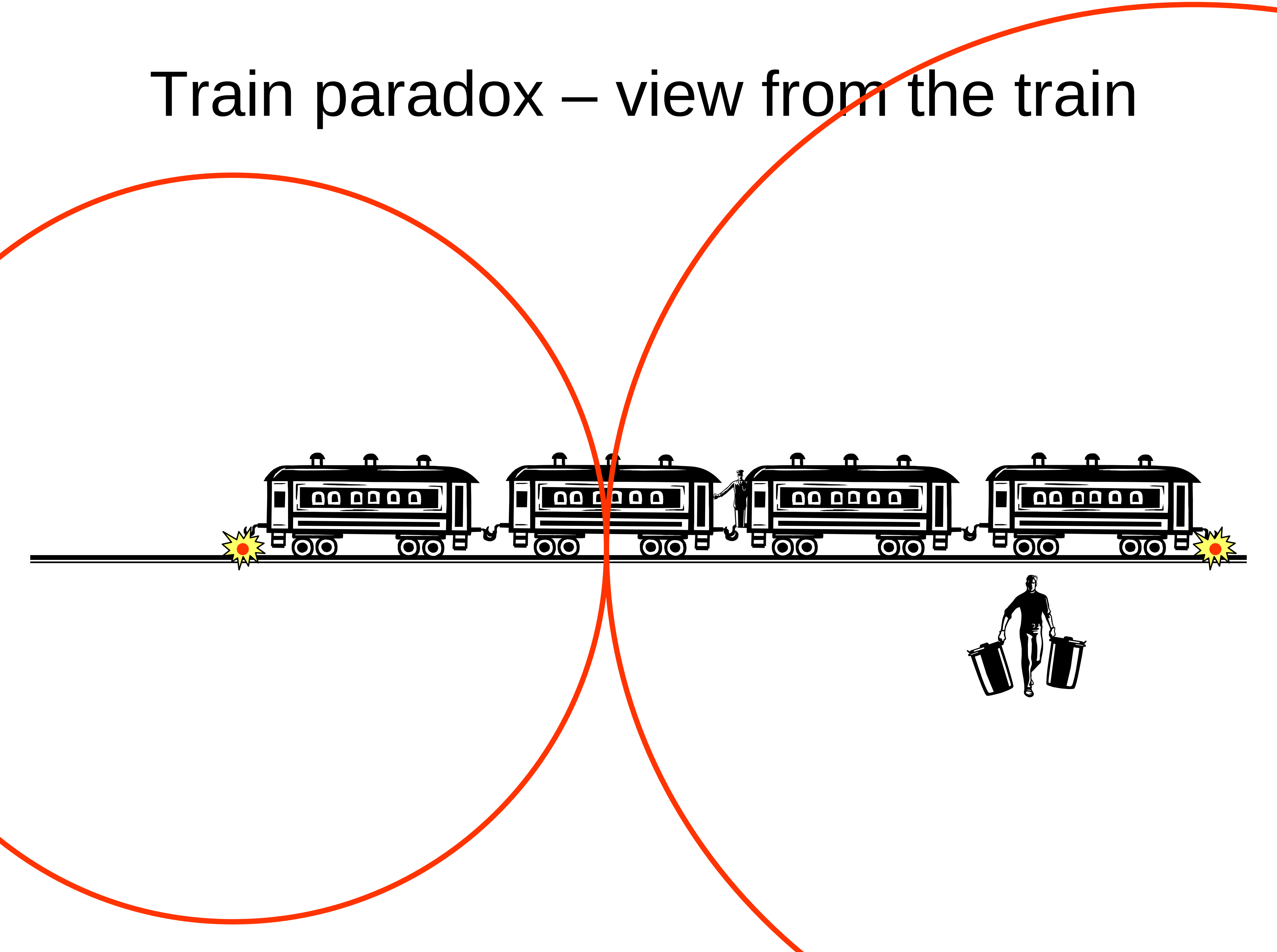
- So, if there *is* relative motion between frames, time separations are not the same – generally. What about a very particular case: ***zero*** time separation (i.e. **simultaneous** events)??? Can zero be *different* in different frames?

- Generally speaking, yes! Only if the space separation is zero (two events taking place in the same point in space), or in the plane perpendicular to the direction of motion, will time separation be zero in all inertial frames (moving along given direction).

Relativity of simultaneity: Einstein's "train paradox"



Train paradox – view from the train



Lorentz contraction

- Lorentz contraction follows from the relativity of simultaneity:

  To measure the length of a moving rod, use the latticework of clocks to mark the locations of the ends of the rod at the same instant.

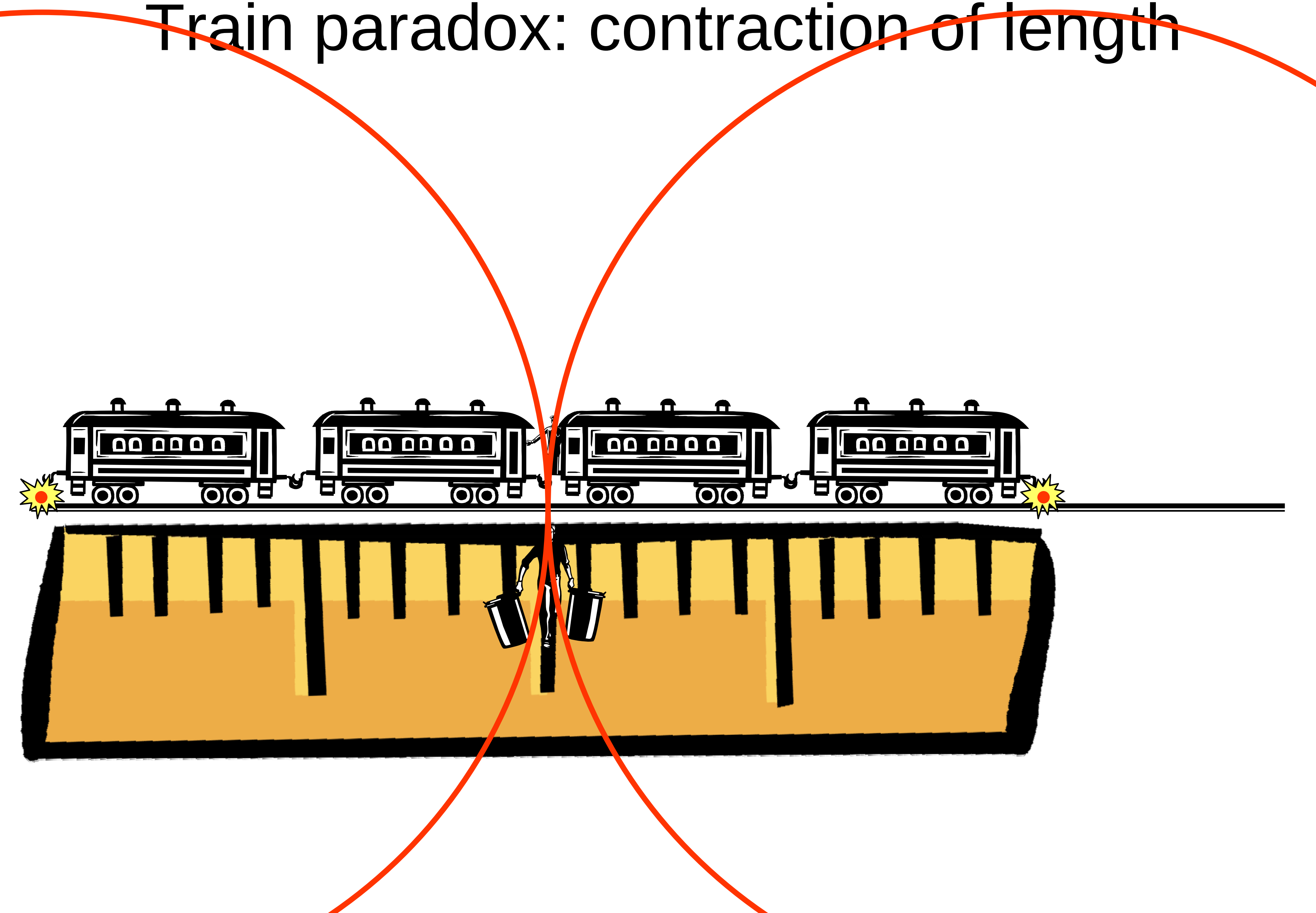
  But it will not be the same instant in the moving frame!

  And vise versa: what was simultaneous in the Rocket frame will not be simultaneous in the Lab frame

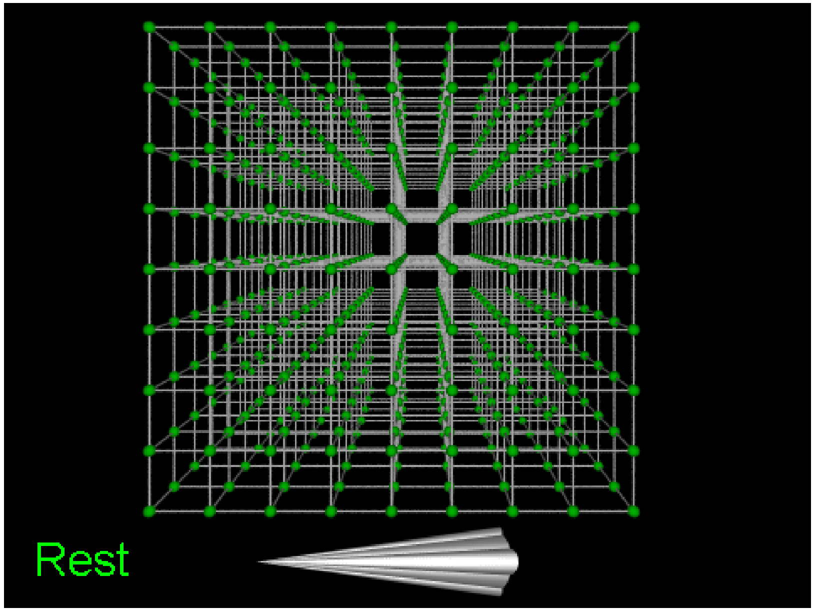
- The result is different length measurements in frames moving relative to one another.

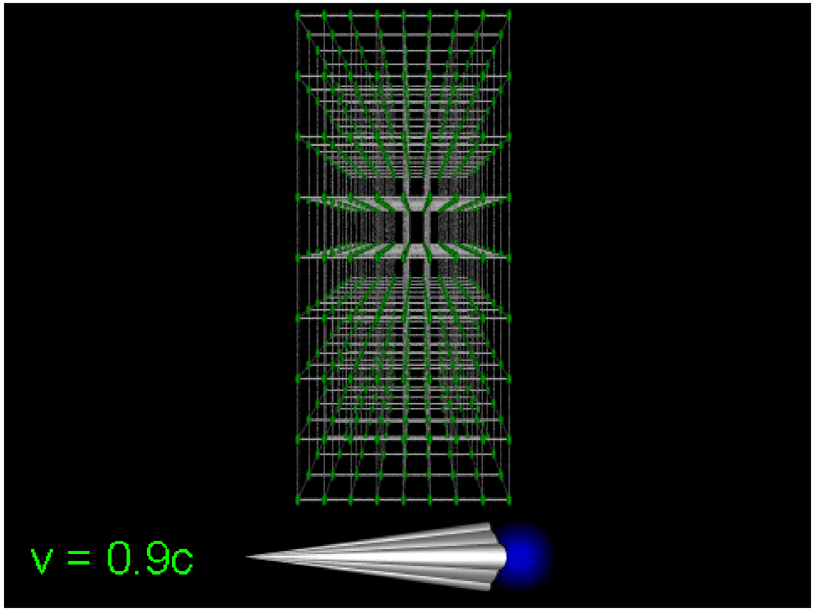
- Length measured in the object's rest frame: the ***proper length***

Train paradox: contraction of length

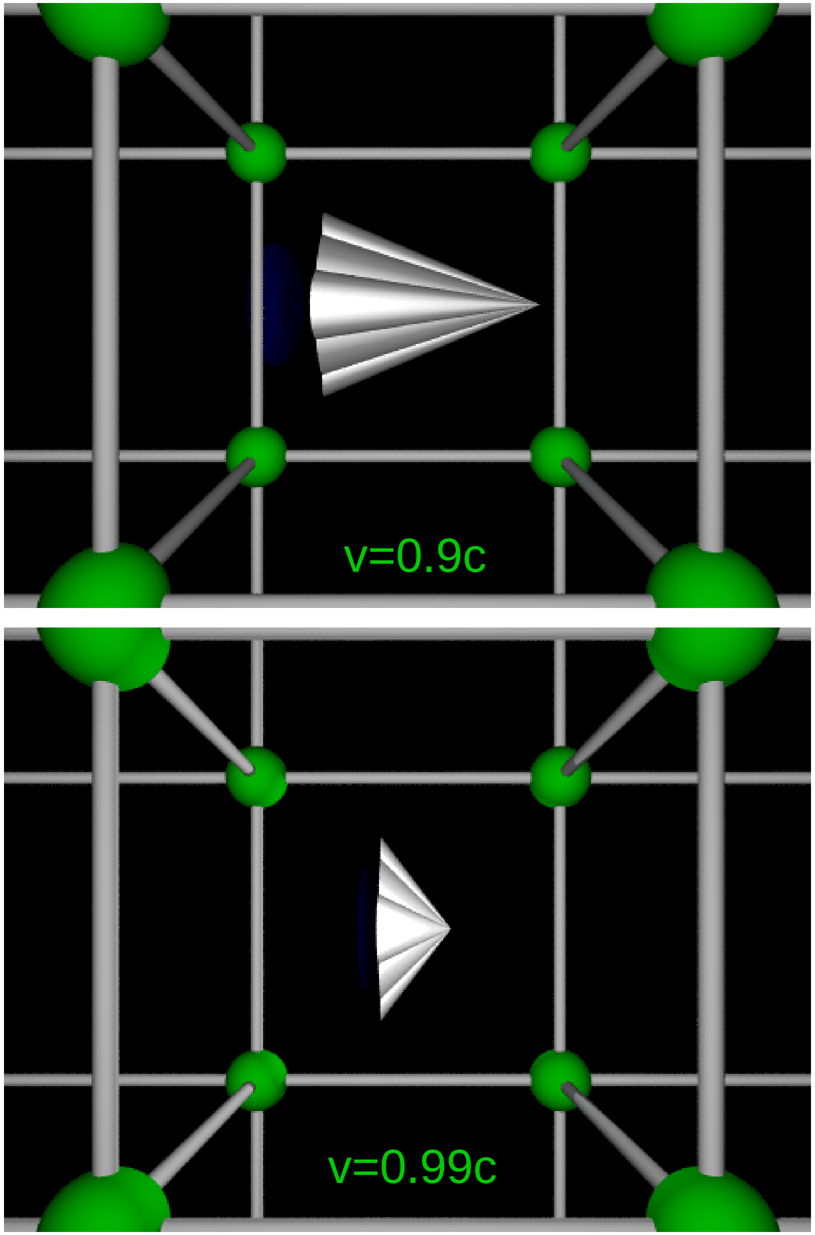


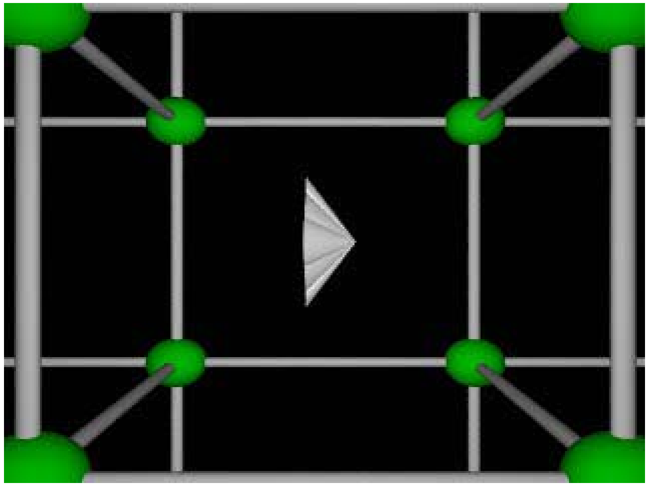
Spaceship, stationary and moving

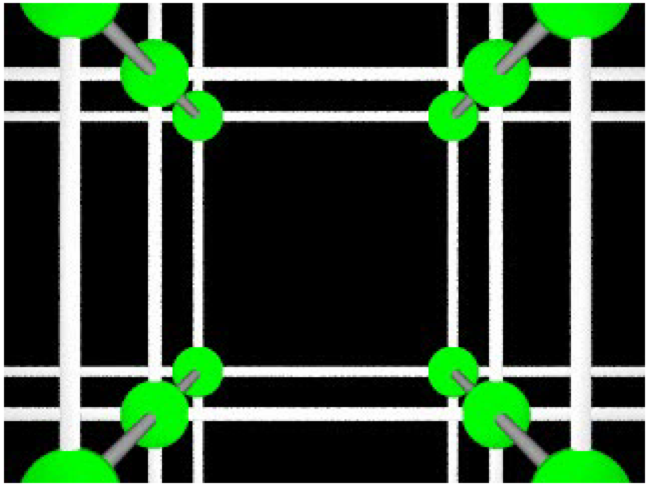




Spaceship, stationary and moving

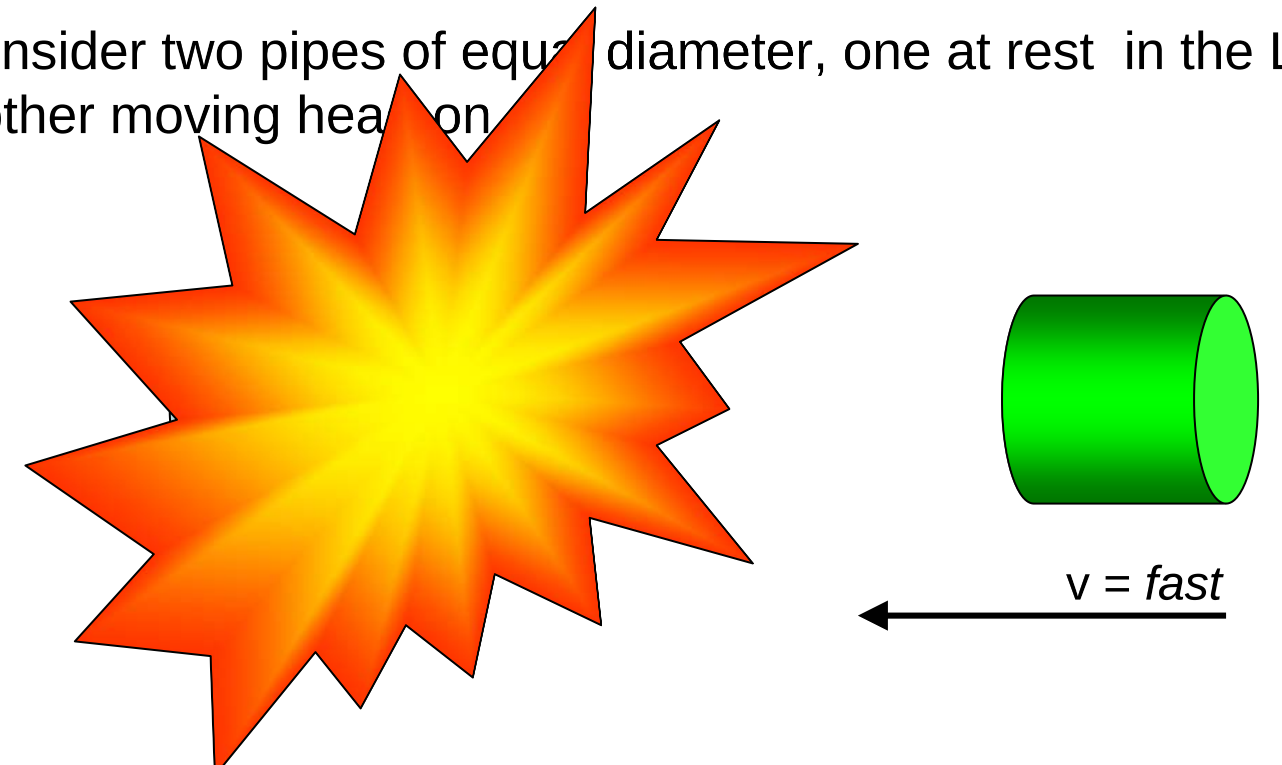






Transverse dimension is unchanged!

- Lorentz contraction observed is only in longitudinal dimension – along the direction of motion.
- Transverse size does not change!
- Consider two pipes of equal diameter, one at rest in the Lab Frame, the other moving head on.



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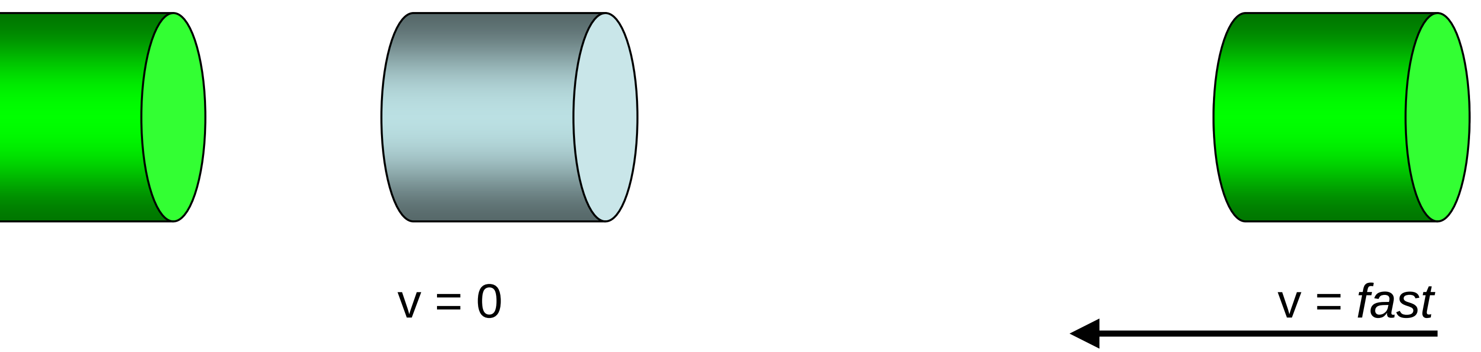

Simultaneity of events in transverse plane

- Imagine a set of events that occurs simultaneously on the rim of the green cylinder (Rocket frame)
- These events are also simultaneous in the blue cylinder frame (Lab frame)! Why?
- Because of the symmetry. There is no preferential direction in space. The space is *isotropic*.
- The absence of Lorentz contraction in the transverse dimension ties together with the simultaneity of events in transverse plane, just like the *presence* of Lorentz contraction in longitudinal direction is tied to the relativity of simultaneity in general.

Recap:

• Postulates of Special Relativity: space and time are uniform, and space is isotropic; law of mechanics and electrodynamics are the same in all frames; speed of light is the same in all frames.

• Solution for the “train paradox” and the explanation of Lorentz contraction: simultaneity is relative

• In the plane transverse to the relative motion of the reference frames simultaneity is conserved.

Tutorial pretest