

Astro 350
Lecture 18
Oct. 5, 2011

Announcements:

- HW5 due next time
- Discussion Question 5 due today

Yesterday: **2011 Nobel Prize in Physics** goes to cosmology!
Saul Perlmutter, Brian Schmidt, Adam Riess

“for the discovery of the accelerating expansion of the Universe
through observations of distant supernovae”

Woo hoo! Party hard but party safe!

acceleration and dark energy will be major focus of A350!

note the use of supernovae as a tool

Q: why? how?

Last time: began Relativity

- space is 3-dimensional Q: *meaning?*
- defined events Q: *what's that?*
- set of all (x, y, z) points Q: *is what?*
- set of all (x, y, z, t) points Q: *is what?*
- Aristotle: space Q: *distances? how related to time?*
Q: *time flow—how depends on space location?*
- Aristotle spacetime diagram Q: *object at rest? const velocity?*
Q: *spacetime diagram of Sun & Earth?*
- light pulse Q: *behavior in space? in spacetime?*

event—localized occurrence in space and time

⇒ unique set of (x, y, z, t) space+time coordinates

Set of all possible events = “**spacetime**”

need 4 coordinates → spacetime is 4-dimensional

spacetime collects info on both space and time

like “stacked” frames of a movie:

each frame is all of space at one instant of time

collection of all frames gives all space at all times

light pulse at $t = 0$ and $(x, y) = (0, 0)$:

in space: expanding circle, radius ct

in spacetime: “stack” of circles with increasing radius

ω

→ shape is a cone: the “light cone”

The Principle of Relativity

existed (in part) even before Einstein:
Galileo knew it, and so did Newton:

“The motions of bodies included in a given space are the same among themselves, whether the space is at rest or moves uniformly forward in a straight line”

–Cosmologist Sir Ike Newton

Q: what's Ike going on about?

Galilean Relativity Principle

- the motion of a *system of bodies* (matter) *relative to each other* is *the same* for any constant-velocity (“inertial”) motion of the entire system
e.g., planet motion vs SS motion
- which means: there is *no experiment* that can detect the *absolute* motion of matter; can only measure motion of particles *relative* to each other
⇒ in closed non-accelerating room: can’t tell if you’re moving!
Contrary to Aristotle!
- T-Shirt/Bumper Sticker/Text Message/Twitter version:
“only relative motion counts” (for matter)

5 But how does *light* weigh in?
Can you use light to tell if a closed room is moving?

The Ether

Consider a moving lightbulb

Newton, Galileo say: if emitter has speed v

then bystander sees light move at speed $c + v$

sped up ahead, slowed down behind

in spacetime: predict light cone “tilted” forward

→ can tell “closed-room” absolute motion

by looking at light

In Newton/Galileo framework:

- light defines (& requires!) a special universal “rest frame”
- in viewpoint where light is wave
needs medium to wave in (e.g., water waves need water)

- late 19th century: **“luminiferous ether”**
invisible, neutral, massless substance
defines absolute cosmic rest frame

Something's Gotta Give

Michelson & Morley experiment (1890s, done in Chicago!)

setup: measure *difference* in speed of light

in two perpendicular directions

repeat for different directions

result: *never see a difference in speeds!*

but: the Earth is moving around Sun

if ether exists, Earth orbit moves us relative to it

light should be slower in direction of Earth motion

yet never seen, so conclude

★ **no experiment can detect ether** or its effects—doesn't exist!

★ speed of light *constant: c , universal*, and

✓ *independent* of motion of observer

Q: *which means in practice?*

Universal speed of light means:

everyone always measures light speed to be same value

$$c_{\text{anybody}} = c_{\text{universal}} = 3 \times 10^8 \text{ m/s} = 186,000 \text{ miles/sec} \quad (1)$$

regardless of motion of emitter, observer

Leads to counter-intuitive (=bizarre) circumstances!

consider “ultrabullet” train

goes at 100,000 miles/sec, shines headlights

★ passengers measure headlight beam speed = 186,000 miles/sec

but also

★ trackside bystanders measure beam = 186,000 miles/sec too!

not Galileo result 286,000 miles/sec!

∞

This is (some of) the weirdness of relativity

Paradigm Shift: Special Relativity

How to cope with lightspeed universality & ether non-existence?

One approach: “separate but equal”

matter and light are fundamentally different

special rules for light

logically possible but lousy idea—if lotsa exceptions

get more general rule

Einstein’s approach: “radical democracy”

Upgrade principle of relativity: *no* absolute rest, motion for *anything* – matter or light

(or anything else you dream up)!

relative motions are all that ever counts!

Special Theory of Relativity a.k.a. “special relativity”

does not yet include gravity! will do this soon, but will require generalized, modified relativity

A Train in a Thunderstorm

Experiment:

- Train, car length L , moving at some speed v past bystander
- two lightning bolts strike front, back of train
- trackside bystander (Brad) stands at midpoint of burn marks
sees flashes simultaneously
- everyone sees light moving at same speed c

iClicker Poll Twofer: Train in a Thunderstorm

Does bystander Brad think flashes are simultaneous?

A yes

B no

Does Angelina in car midpoint think flashes simultaneous?

A yes

B no

The Relativity of Simultaneity

bystander Brad: two flashes each travel same distance $L/2$

so take same time $t = L/2c$

⇒ Brad sez: they're so totally **simultaneous**, dude!

passenger Angelina: train motion carries her

toward front flash, away from back flash

⇒ sees front flash first, then back flash later

But she thinks flashes traveled each same distance $L/2$

so concludes they took same travel time $L/2c$

⇒ Angelina sez: you lying dog, they're totally **not simultaneous!**

Q: *so who's right?*

Q: *what's the larger lesson?*

Who's right? Neither lying (about this), but disagree

- “simultaneous” is not a universally agreed condition
- **relativity of simultaneity**
- observers with different motion perceive time differently

More Philosophical Commentary on Time

Strange things are afoot at the Circle-K.

– Cosmologist Ted “Theodore” Logan

Mirrors as Clocks

build “clock” in train car, height L

- mirrors on floor, ceiling reflect light up & down
- one “tick” per light bounce

www: light clock animation

in train frame: **clock at rest** (so $x = \text{constant} = 0$)

- light pathlength $d = \sqrt{x^2 + y^2} = y = L$
- tick duration $(\Delta t)_{\text{rest}} = L/c$ (since $d = c\Delta t$)

in trackside frame, **train moving at speed v**

- light zigzag due to mirror motion \rightarrow path longer!

Q: why? what will this mean?

in trackside frame, **train moving at speed v**

- during tick time $(\Delta t)_{\text{moving}}$ horizontal motion $x = v(\Delta t)_{\text{moving}}$
- light pathlength

$$d = \sqrt{x^2 + y^2} = \sqrt{v^2(\Delta t)_{\text{moving}}^2 + L^2} \quad (2)$$

- tick duration $(\Delta t)_{\text{moving}} = d/c$, which means

$$d^2 = c^2(\Delta t)_{\text{moving}}^2 = v^2(\Delta t)_{\text{moving}}^2 + L^2 \quad (3)$$

$$(c^2 - v^2)(\Delta t)_{\text{moving}}^2 = L^2 \quad (4)$$

which gives

$$(\Delta t)_{\text{moving}} = \frac{L}{\sqrt{c^2 - v^2}} = \frac{c}{\sqrt{c^2 - v^2}} \frac{L}{c} \quad (5)$$

$$= \frac{(\Delta t)_{\text{rest}}}{\sqrt{1 - \frac{v^2}{c^2}}} \quad (6)$$

Q: which means? and is bizarre because?

time dilation

we find

$$(\Delta t)_{\text{moving}} = \frac{(\Delta t)_{\text{rest}}}{\sqrt{1 - \frac{v^2}{c^2}}} \quad (7)$$

$$= (\text{number} > 1) \times (\Delta t)_{\text{rest}} \quad (8)$$

$$> (\Delta t)_{\text{rest}} \quad (9)$$

- ★ moving clocks don't appear to keep same time as clocks at rest! Namely,
- ★ moving clock appears to have longer ticks!
- ★ moving clocks appear to run slow!
- ★ time depends on state of motion! not universal!