

Astro 350  
Lecture 17  
Oct. 3, 2011

Announcements:

- HW5 available, due Friday
- Discussion Question 5 due Wednesday
- Hour Exam 1 back today

**Tomorrow:** top NASA cosmologist in the house!  
Dr. Jonathan Gardner

- *Public Talk:* Tue Oct 4, 7:30pm, 151 Loomis (Physics bldg)  
“A Scientific Revolution: the Hubble and James Webb Space Telescopes”
- *Astro Colloquium:* Tue Oct 4, 4pm, 134 Astronomy bldg  
“The James Webb Space Telescope”
- └ ● *informal seminar:* Tue Oct 4, 2pm, 134 Astronomy bldg  
“How to get a job working for NASA”

## Space/Time: Gut Reactions and Common Sense

Go with your gut:

*Q: what is the nature of space?*

e.g.: dimensionality? size? distances between points?  
properties here vs elsewhere?

Still go with your gut:

*Q: what is the nature of time?*

e.g.: when are goings-on “simultaneous”?  
properties of time here vs elsewhere?

# Space

Gut expectations from everyday life

Space is:

- three dimensional—i.e., extends in 3 independent directions  
points described with 3 coordinates, e.g.,  $(x, y, z)$
- geometry according to Euclid—e.g., circumference/diameter= $\pi$   
triangle internal angles sum to  $180^\circ$
- infinite in size, volume  
e.g.,  $(x, y, z)$  Cartesian grid extends without limit

Before the end of the semester

ω *all* of the above will be called into question!

## Space: Wit and Wisdom

Absolute space, in its own nature,  
without relation to anything external,  
remains always similar and immovable.

Relative space is some movable dimension or measure  
of the absolute spaces ...

– Cosmologist Sir Isaac Newton

*Q: What's Ike talking about?*

*what's absolute vs relative? examples?*

## Time: Bigwigs Weigh In

What then is time?

If no one asks me, I know what it is.

If I wish to explain it to him who asks,  
I do not know.

– Cosmologist St. Augustine

Absolute, true and mathematical time,  
of itself, and from its own nature,  
flows equally, without relation to anything external.

– Cosmologist Sir Isaac Newton

Time keeps on slippin slippin slippin  
Into the future

– Cosmologist Prof. Steve Miller

# Time: Commonsense Expectations

Time: Gut Expectations

- universal—“flows at same rate” everywhere  
e.g., as 1 hour passes here, 1 hour also passes  
in Chicago, North Pole, the Moon, M31, ...  
don't need new watch when travel out of state
- simultaneous=clocks all read the same  
since time universal, can coordinate all clocks to read same  
and once set, will always stay synchronized

By the end of the week: will find these ideas untenable!

# Space, Time, and Motion

motion links space and time  
and so depends on nature of space and time

## Pre-Relativity: Aristotle

Aristotle: Ancient Greece

ideas based on everyday experience, common sense  
(paraphrased here to anticipate where we are going)

natural state of motion: rest

e.g., ox carts, arrows, anchors come to rest on Earth's surface

→ absolute space exists, defined by "frame"

in which objects naturally at rest

and absolute time exists too:

time "flow" is same always, everywhere, for everyone

## Aristotleian Space: Description

to completely specify the *address* or *location*  
of any point in space  
need to give *three numbers*  
thus we say  $\Rightarrow$  space is **three dimensional**

examples of 3-numbered addresses:

- in city: 1. street, 2. number on street, 3. floor of building
- on GPS device: 1. latitude, 2. longitude, 3. altitude

Why? Space has 3 independent directions

left-right, up-down, back-front

need to give location in all three direction (dimensions)  
to completely specify a point

- $\infty$  If label points with 3-D  $(x, y, z)$  Cartesian grid
- Aristotleian space: **set of all possible  $(x, y, z)$  addresses**
  - fixed “stage” for goings-on in time  $t$



# Extreme Makeover for Aristotle: Events and Spacetime

Useful idea (not Aristotle's, but he wouldn't object)

**event**—localized occurrence in space and time

e.g., firecracker, finger snap

idealized → no spatial extent, no duration in time

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

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

*Plot: Aristotle spacetime:  $x - y$  plane in perspective,  $t$  up*

Note: need 4 coordinates → spacetime is 4-dimensional

...even for Aristotle!

but as yet nothing odd or Science-Fictiony

just a mathematical labeling of the familiar

## iClicker Poll: Aristotle and Simultaneity

In an Aristotelian world:

is it meaningful for events to “simultaneous” = at the same time?

A yes

B no

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*Q: if not, why not? what's the problem?*

*Q: if so, how do you tell?*

## Life According to Aristotle

consider two events (plot in spacetime)

firecracker 1:  $(x_1, y_1, z_1, t_1)$

firecracker 2:  $(x_2, y_2, z_2, t_2)$

*Q: What is spatial distance between events?*

*Q: What is duration/elapsed time between events?*

*Q: How to tell if events simultaneous?*

two events:

firecracker 1:  $(x_1, y_1, z_1, t_1)$

firecracker 2:  $(x_2, y_2, z_2, t_2)$

spatial distance  $\ell$  between events:

$$\ell^2 = (x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2 \quad (1)$$

- à la Pythagoras
- result indep of time coordinates  
→ encodes idea of “absolute space”

elapsed time between events:  $t_2 - t_1$

simultaneous: no elapsed time →  $t_2 = t_1$  (same time coord)

- indep of space coordinates → encodes idea of “absolute time”

Now consider one particle during some time interval

*Q: how to tell if it is at rest?*

*Q: as time flows, what is path of particle at rest*

*in spacetime? what if const velocity? accelerated?*

objects (observers) **at rest**:

same  $x, y, z$  always,  $t$  ticks forward

geometrically, **a vertical line** in spacetime

observers moving at **constant velocity**:

e.g., same  $x = vt$ , and  $t$  still ticks forward

geometrically, **a diagonal line** in spacetime

slope from vertical is speed  $v$

**accelerated** observers: changing velocity

→ line with changing slope—**curved line** in spacetime

in general:

particle/observer represented by

(possibly curved) line in spacetime: **world line**

Still—no funny business yet, just a way of describing boring, familiar events in spacetime

*Q: spacetime of pop fly, centerfielder?*

## Light and Spacetime

consider flash of light, emitted from lightbulb at rest  
spherical pulse spreads at constant speed

$$c_{\text{emitter at rest}} = 3 \times 10^8 \text{ m/s} = 186,000 \text{ miles/sec} \quad (2)$$

*diagram: pulse in space*

in spacetime: pulse traces a “V”-shaped wedge

in  $x - t$ ,  $y - t$  planes

so in  $(x, y)$  vs  $t$ : traces a cone

→ light pulse moves along the “light cone”