Astro 350

Lecture 15

Oct. 3, 2012

Announcements:

- **HW 4** available, due at start of class Friday
  instructor office hours today 1-2pm
  TA office hours tomorrow 9:30–10:30am
- no Discussion was due today
- **Discussion 5** available today, due next Wednesday

Last time: stars and cosmology

Q: What is a supernova? Why are supernovae important?

Q: Why are supernove good cosmological tools?

Q: How can we find supernovae when can't predict them?

Finding Cosmic Supernovae

Massive star appearance (luminosity, temperature) doesn't change over last several 100,000 years of lifespan
$\rightarrow$ cannot when massive stars will die in supernovae explosions

Observational Strategy:
- monitor many many galaxies
  $\rightarrow$ **survey** wide area of sky
- observe each every few days: repeatedly **scan**
- look for appearance, brightening, and disappearance of supernovae
- huge amounts of data $\rightarrow$ huge challenge to process

powerful computers and huge digital cameras make this possible
e.g., can digitally "subtract" before/after images
$\rightarrow$ difference shows what's changed: SN

`www: SN search teams`

Standard Candles and Astronomical Distances

Supernovae* have very useful property
$\Rightarrow$ peak luminosity $L_{\rm peak}$ always the same ...as best can tell so far...
an extremely useful property!

recall: apparent brightness (flux F) depends on luminosity
but also on distance: $F = \frac{L}{4\pi R^2}$

$\star$ imagine object with known luminosity: "standard candle"
e.g., 100 Watt lightbulb, or SN at peak `www: cartoon`
$\rightarrow$ can measure flux $F_{\rm obs}$, and using known $L_{\rm candle}$
solve for distance $R = \sqrt{\frac{L_{\rm candle}}{4\pi F_{\rm obs}}}$

Supernovae are great standard candles because
give distance measures across the universe

*In fact: a special kind of supernova: "Type Ia" = exploding white dwarfs

Supernovae Observed Across the Universe

Results thus far:

- ⋆ supernovae seen out to great distances $\rightarrow$ early times
  star birth indeed occurred in the past, not just now!

- ⋆ in fact, birthrate *much* higher in the past!

- ⋆ also: SN as standard candles give very interesting result ...
  will provide most direct evidence for bizarre dark energy!

The Surveying Illini

UofI involved in two major sky *surveys*

Dark Energy Survey `www: DES`

location: Cerro Tololo, Chile $\rightarrow$ southern celestial hemisphere

telescope: 4 meter diameter

camera: 570 Megapixel

scan mode: monitor $40\,\mathrm{deg}^2 = 80\times$ full moon

first light: *two weeks ago! comissioning under way!*

Large Synoptic Survey Telescope `www: LSST`

location: Cerro Pachón, Chile

telescope: 8 meter diameter $\rightarrow 4\times$ more collecting area

camera: 3200 Megapixel

scan mode: monitor $20,000\,\mathrm{deg}^2 =$ *entire southern sky*

under construction: first light expected 2019

Q: what will these surveys find?

Anticipated Survey Results

Deep *maps* of the *unchanging* sky will show
- stars in Milky Way
- nearby and distant galaxies
- the large scale structure of the Universe
- surprises we have not anticipated

But scanning will reveal, for the first time
movies of the entire (southern) sky
$\rightarrow$ we will see anything that changes over 10 year survey time
- comets & asteroids in solar system
- variable stars
- supernovae (and other explosions: novae, gamma-ray bursts, other?)
- surprises we have not anticipated

Predictions (Dr. Amy Lien, UIUC PhD & BDF):
▷ DES: about 5000 supernovae per year! out to 4000 Mpc!
▷ LSST: about 500,000 supernovae per year! to $>$ 4000 Mpc!

Research Opportunities for Undergraudates

DES and LSST opportunities here and now!

DES comissioning going faster than expects
"production run" collecting science data starts this December
and will run for 5 years

LSST under construction
but now is the time to "get in on the ground floor"

Lots of work to do for smart young cosmologists!

Lineup of Dark Matter Suspects

~~hot gas~~

~~cold gas~~

black holes
neutron stars
white dwarfs
"failed stars" – "Jupiters," brown dwarfs
} compact objects

neutrinos

relic particles from big bang

- compact objects arising from star formation
- are small $\rightarrow$ easy to miss
- but Einstein taught us a way to find them!

Relativity

Space/Time: Gut Reactions and Common Sense

Relativity is a theory of space, time, and matter

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 (i.e., as learnt in high school)
  circle circumference/diameter=π
  triangle internal angles sum to 180°
- infinite in size, volume
  e.g., (x, y, z) Cartesian grid extends without limit

Before the end of the semester
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 galaxy, ...
  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., oxcarts, arrows, anchors come to rest on Earth's surface
$\rightarrow$ 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

If label points with 3-D (x, y, z) Cartesian grid
- Aristotelian 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 $\rightarrow$ no spatial extent, no duration in time

$\Rightarrow$ 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 $\rightarrow$ spacetime is 4-dimensional

...even for Aristotle!

but as yet nothing odd or Science-Fiction-y

just a mathematical labeling of the familiar

iClicker Poll: Aristotle and Simultaneity

In an Aristotelian world:

is it meaningful for events to be "simultaneous" = at the same time?

A yes

B no

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 ℓ between events:

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

- à la Pythagoras
- result indep of time coordinates
  $\rightarrow$ encodes idea of "absolute space"

elapsed time between events: $t_2 - t_1$
simultaneous: no elapsed time $\rightarrow t_2 = t_1$ (same time coord)
- indep of place in space (i.e., coordinates)
  $\rightarrow$ encodes idea of "absolute time"