Astro 350

Lecture 23

Oct. 17, 2011

Announcements:

- Discussion Question 7 due today
- HW7 due Friday
- Office Hours: instructor–after class today
  TA: 2-3pm tomorrow

Last time:

General Relativity curved spacetime example #1: black holes

Today and the rest of the Semester:

General Relativity curved spacetime example #1: the Universe

General Relativity: Executive Summary

General Relativity = Einstein's gravity theory

- agrees with all known experiments/observations (so far)
- gravity $\neq$ force, but rather "spacetime curvature"
- matter tells spacetime how to curve
  curvature tells matter how to move
- in GR, the nature of spacetime:
  - is dynamic, i.e., spacetime responds to matter within it
  - cannot be deduced from pure thought, but
  - must be experimentally measured/mapped,
    i.e., the nature of space and time can be different
    depending on the matter/energy content of the Universe;
    have to measure our Universe and its contents
    to see what we have been dealt

Modern Cosmology

Cosmology: The Big Picture

Take science to the largest arena possible:
study the Universe as a physical system

- structure
- dynamics
- composition
- origin
- evolution

The Large-Scale Structure of the Universe: I

Observations teach us that, to a "first approximation":
the Universe *today* is

1. homogeneous: average properties same at all points
e.g., mass density anywhere is same as mass density everywhere!

and

2 isotropic: looks same in all directions

universe is homogeneous & isotropic:
the **"cosmological principle"**
first guessed(!) by A. Einstein (1917)

Q: as exact (not approximate) statement,
cosmo principle obviously false! Why?
In what sense could it be true?

Example: Cosmo principle and galaxy properties

Q: if cosmo princip true, how reflected in observations of galaxies at any given time?

Q: how could you test this?

Q: what does cosmo principle say about how galaxy properties evolve with time?

Cosmo principle and galaxy properties:

at any given time:

- **average** density of galaxies same everywhere
- distribution of galaxy properties same everywhere

e.g., types, colors, L, M, ...

- time evolution: must maintain large-scale homogeneity and isotropy

but otherwise, **by itself** principle allows any changes!

Real Galaxies in the Real Universe

Beyond the First Approximation

cosmo principle a very good approximation

on large scales ($\gtrsim 30$ Mpc)

`www: 2dF`

but do observe fluctuations around average galaxy density

`www: 2dF maps`

on small to medium scales ($\lesssim 30$ Mpc),

galaxies **clustered** in space:

- loners: "field" galaxy
- few ($\lesssim 50$) galaxies: group
- 100's-1000's of galaxies: cluster
- assemblies of groups and clusters: supercluster

The Logic of the Cosmo Principle

Cosmo Principle:
On large scales ($\gtrsim 30$ Mpc), universe is
- homogeneous $\rightarrow$ smooth
- isotropic

Q: do you need both?
Q: e.g., how can you be isotropic but not homogeneous?
Q: e.g., how can you be homogeneous but not isotropic?

Cosmo principle as cosmic democracy:
Universe has no center, no edge
no special places, directions!

The cosmo principle, in song

I'm just average, common too
I'm just like him, the same as you
I'm everybody's brother and son
I ain't different from anyone
It ain't no use a-talking to me
It's just the same as talking to you.

Cosmologist Prof. Bob Dylan (1964)

Cosmological Principle: Implications

- demands enormous regularity

"maximal symmetry" $\rightarrow$ simplifies analysis!

- places stringent constraints on
  (i.e., simplifies!) the possible nature and behavior
  of the Universe and its contents
  i.e., is "the cosmologist's friend"

- "trying to tell us something"
  about how universe formed?
  (e.g., cosmic inflation in early universe?)

iClicker Poll: Cosmodynamics

galaxies have mass $\rightarrow$ gravitate
in general, expect galaxies to be in motion

What pattern of motions (relative to us) will we find?

A most galaxies move towards us

B roughly half move away, half towards us

C most galaxies move away from us

iClicker Poll: Cosmodynamics Twofer

in fact: the *majority* of galaxies move away from us

What percentage of galaxies are observed to move away?

A between 50% and 75%

B between 75% and 90%

C between 90% and 95%

D between 95% and 99%

E $>$ 99%

Cosmodynamics I

of >1 million galaxies with redshift/blueshift measurements

<20 galaxies have blueshifts! (only nearest ones)

so: $>99.9999\%$ of galaxies have redshifts!

$\Rightarrow$ essentially all galaxies have **redshift**:

$$z \equiv \frac{\lambda_{\rm obs} - \lambda_{\rm rest}}{\lambda_{\rm rest}} > 0 \qquad (1)$$

$\rightarrow$ move away!

line-of-sight speed: Doppler law sez $v = cz$

first approximation:

Hubble (1929) v & distance r related:

`www: Hubble original data`

Q: how are v and r related mathematically?

Hubble: galaxy speed and distance *proportional*
$\Rightarrow v \propto r$

$\boxed{v = H_0 r}$ Hubble law

in fact: $\vec{v} = H_0 \vec{r}$
that is, speed and distance directions the same
$\rightarrow$ galaxies all move *radially* away from us!
Q: why did it have to be this way?

Hubble Law $v = H_0 r$

Hubble parameter (a.k.a. "Hubble constant")

$$H_0 \simeq 72 \text{ km s}^{-1} \text{ Mpc}^{-1} \tag{2}$$

e.g., galaxy at $r = 10$ Mpc moves away at 720 km/s

Try it!
draw field with MW, other galaxies, $\vec{v}$
Comment on pattern

Note: to zeroth order, z + Hubble law $\rightarrow r$
distance measure

Structure + Dynamics: Evolution

observe:

- U. homogeneous, isotropic
- Hubble law $v = Hr$

i.e., galaxies smoothly spread in space, yet moving too
and motions are all directed away from us!
i.e., galaxy velocity pattern "points back to us"

Q: how reconcile?
at least 2 logical possibilities...

1. "Egoist" interpretation: we are at the center of U.
galaxy motion implies explosion which centered on us!
if $v_{\mathrm{gal}} = const$, all start at $r = 0$
at time $t_{\mathrm{H}} = 1/H_0 = 14 \times 10^9$ yr $= 14$ Gyr ago
"Hubble time"

Logically possible! But...
Q: give a philosophical reason why we don't believe this
Q: give a physical reason why this treatment can't be right?
Q: give an observational reason why we don't believe this