Astro 507

Lecture 13

Feb. 19, 2014

Announcements:

- **Problem Set 2 due Friday**

  office hours: 3:10-4pm Thurs., or by appt

  for problem 1: see also extras in Lecture 12

Today: dark energy begins!

Last time: cosmic distances

Q: "Newtonian" distance?

Q: luminosity distance?

Q: angular diameter distance?

Cosmic Distances

Newtonian distance

$$d_{\mathsf{Newt}} = \frac{cz}{H_0} = d_{\mathsf{H}}\ z$$

luminosity distance

$$d_{\mathsf{L}} = \sqrt{\frac{L_{\mathsf{em}}}{4\pi F_{\mathsf{obs}}}} = (1+z)\ r(z)$$

angular diameter distance

$$d_{\mathsf{A}} = \frac{D_{\mathsf{em}}}{\delta\theta} = \frac{r(z)}{1+z}$$

where comoving radial coordinate:

$$r(z) \overset{\mathsf{flat}}{=} c \int_0^z \frac{dz'}{H(z)'} \tag{1}$$

Note: $d_{\mathsf{L}}/d_{\mathsf{A}} = (1+z)^2$ for any cosmology
"reciprocity relation," sometimes called "distance duality"

Now: finished cosmo muscle building
▷ passed Olympic trials
▷ onward to Sochi!

ASTR 507 thus far: classical cosmology observations, Newtonian & Relativistic theory

Beginning now: 21st Century Cosmology

Cosmic Acceleration & Dark Energy

Cosmic Conundrum: Observations vs Good Taste

1990's Cosmology:

▷ theory (Dicke coincidence *Q: whazzat?*, inflation), good taste, and some observational hints on large scales
$\rightarrow \Omega_0 = 1$

▷ observation (e.g., galaxy halos, clusters) $\rightarrow \Omega_m \sim 0.3$

Q: possible reasons for discrepancy?

Q: observational tests?

Probing Cosmic Expansion as Far as the Eye Can See

Friedmann: cosmic *contents* control cosmic *dynamics*
$\rightarrow$ cosmic ingredients encoded in *history* of cosmic expansion

Strategy: **measure** $H(z)$ over large range in z

- Friedmann: $H = H(z; \Omega_0) \rightarrow$ data over large z range determine Ω_0
- alternatively, Friedmann accel:

$$H^2 = -2\frac{\ddot{a}}{a} - 8\pi G P - \frac{\kappa c^2}{R^2 a^2}$$

$H(z)$ sensitive to acceleration, pressure, curvature

Q: what observables trace $H(z)$? what needed for large z range?

Supernovae as Standard Candles

long "baseline" in z $\to$ requires **luminous** sources
supernova explosions–can outshine a galaxy
at peak, $L_{\text{SN,max}} \sim 10^{10} L_\odot$
`www: SN 1994D; SN2014J in M82`

Procedure:

- identify SNe to use as standard candles
- measure flux F for events over wide range in z
- find $d_L(z) = \sqrt{L_{\text{SN}}/4\pi F} \overset{\text{flat}}{=} (1+z)\int_0^z dz/H(z)$
- infer $H(z)$ $\to$ cosmic dynamics, parameters

First step:
all SN not created equal!
Q: what are basic SN classes observationally? how distinct physically?

Supernova Zoology 101

- **Type II* (Core-Collapse) Supernovae**
  massive star $\gtrsim 8 - 10 M_\odot$ gravitational collapse
  optical (baryonic) explosion: $E_{\rm vis} \sim 10^{51}$ erg
  but most energy released in neutrinos: $E_\nu \sim 3 \times 10^{53}$ erg
  neutron star/black hole remnant

  *Types Ib and Ic events also due to core-collapse

- **Type Ia (Thermonuclear) Supernovae**
  binary system: white dwarf and companion
  WD accretes $\rightarrow$ pushed over Chandrasehkar limit
  i.e., drive $M_{\rm WD} > 1.4 M_\odot \rightarrow$ gravitationally unstable
  thermonuclear detonation $E_{\rm exp} \sim 10^{51}$ erg

∞

Q: pros and cons of each Type for cosmology?

Supernova Cosmology: The Good, the Bad, and the Ugly

Type II Supernovae

Pro

- Understand basic physics:
  most E_{SN} in neutrinos
  saw 1987A neutrinos
  confirmed basic picture

Con

- Don't understand optical explosion:
- $E_{\text{vis}} \sim 1\% E_{\text{SN}}$ tough!
  models often don't explode!
- core collapse: range of masses, E_{SN}

$\Rightarrow$ diverse range of $L \Rightarrow$ candle not std

occur in $\star$-form regions $\rightarrow$ obscured

Type Ia Supernovae

Pro

- Chandra limit $\sim$ fixed mass
  $+$ nuke binding $\sim$ fixed
  $\approx$ fixed E release
  $\Rightarrow$ fixed $L(t)$: std candle!
- low-z SN Ia nearly identical $L(t)$
- outside $\star$-form: less(?) osbscured

Con

- Don't understand basic
  scenario: who is companion?
  giant? another WD?
  astrophysical "black box"
- low-z Ia *not* identical $L(t)$

Type Ia Supernovae: "Standardizable" Candles

Type Ia events: best candidates on balance (for now)

- empirically (low-z) closest to std candles
- typically ~ 1 mag brighter than SN II $\rightarrow$ can probe higher z
- ...but check for systematics!

Type Ia light curves (low-z): *E Pluribus Unum*

light curve $L(t)$ same basic shape–rise, fall

... but spread in timescale ($\sim$ FWHM) & peak L

... but these are tightly *correlated*!

$\rightarrow$ $L(t)$ spread can be empirically fit with 1 parameter

$\Rightarrow$ *scaled* light curves $\approx$ identical! `www: light curves`

$\Rightarrow$ "**standardized**" candles!