Announcements

- Exam #3 will be in class on Wednesday, November 30.
- Office hours in 702 VAN: Tuesday 1-3 pm, Wednesday 10-11 am, or by appointment.
- Astronomy tutorial Tuesday 3-5 and 7-9 pm in 310 VAN.

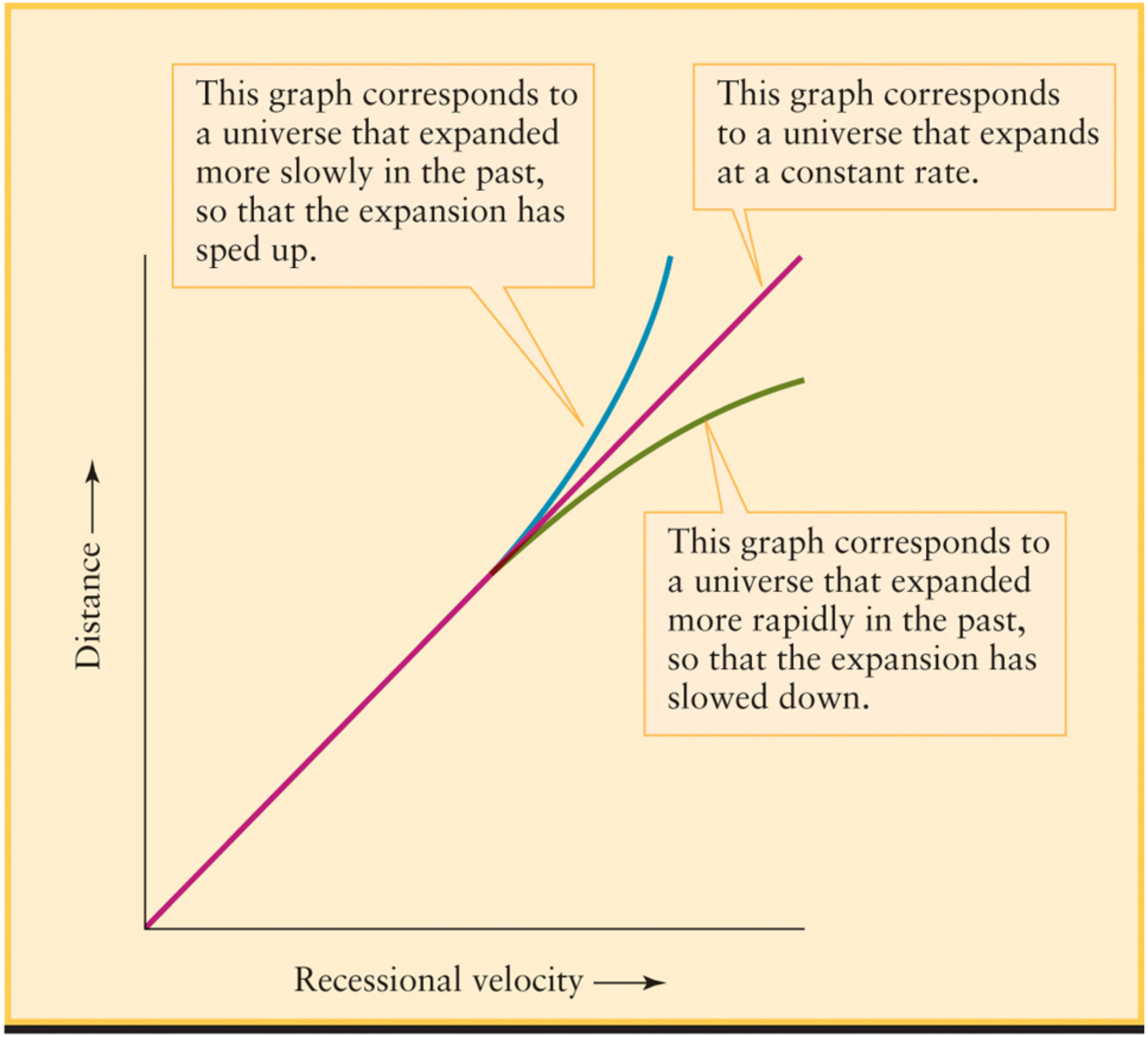
- Final exam will be Wednesday, December 14, at 9:45 am in LR1 VAN.

Expansion of the Universe

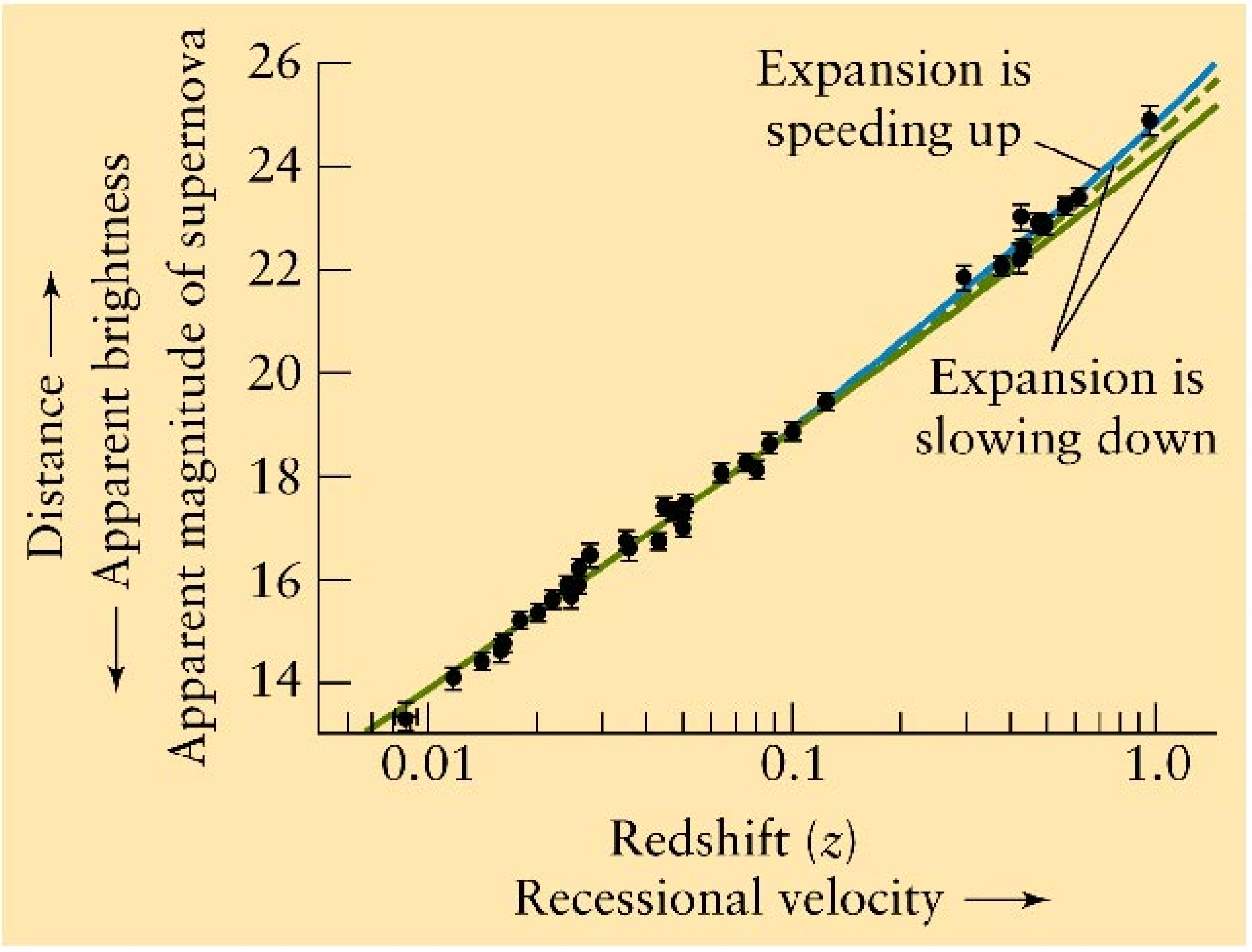
Larger distance means we are looking further into the past.

Decelerating Universe:
If the rate of expansion of the universe was faster in the past, we should see larger velocities for larger distances.

Accelerating Universe:
If the expansion rate was slower in the distant past, we should see lower velocities for large distances.



(b) Possible expansion histories of the universe


Expansion is
speeding up
Expansion is
slowing down
26
24
22
20
18
16
14
0.01
0.1
1.0
Redshift (z)
Recessional velocity →
Distance →
← Apparent brightness
Apparent magnitude of supernova

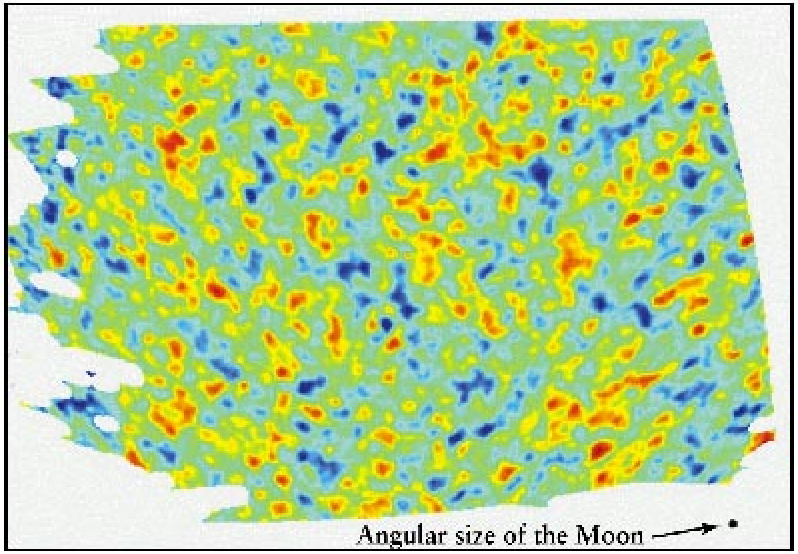
The fact that Type Ia supernovae at a large distances have ____________ redshifts than expected for a Universe expanding at a constant rate showed that the expansion of our universe is accelerating.

A) tastier

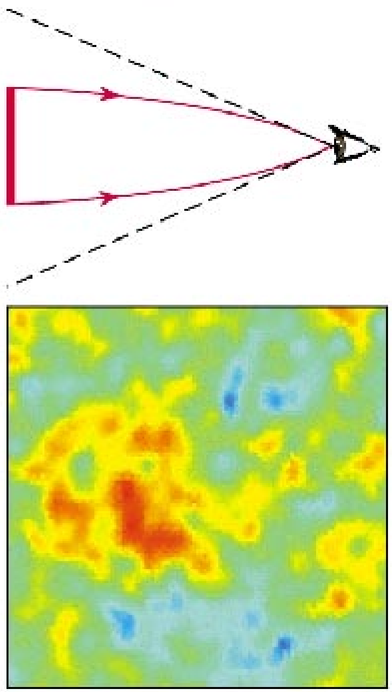
B) the same

C) larger

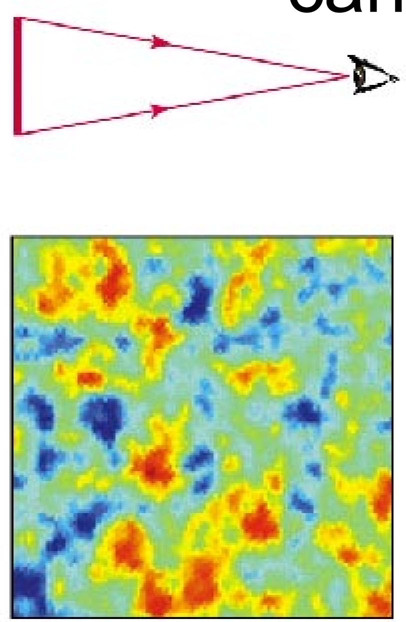
D) smaller



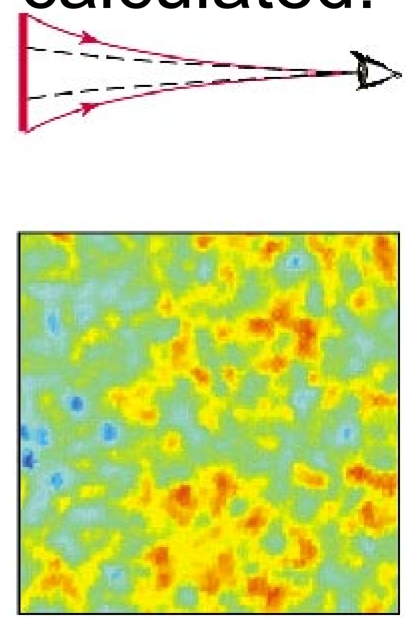
Temperature variations in the Cosmic Microwave Background (CMB) are observed to be about 0.0003 K. The expected physical size of the hot/cold regions can be calculated.



a If universe is closed, “hot spots” appear larger than actual size



b If universe is flat, “hot spots” appear actual size



c If universe is open, “hot spots” appear smaller than actual size

Curvature of the Universe

The curvature of the Universe is determined by the density parameter Ω_0

$$\Omega_0 = \frac{\rho}{\rho_C}$$

$\Omega_0 < 1 \Rightarrow$ negative curvature

$\Omega_0 > 1 \Rightarrow$ positive curvature

Measurement of CMB fluctuations gives

$$\Omega_0 = 1.02 \pm 0.02$$

Observations of hot spots in the Cosmic Background Radiation suggest that we live in a ___________ universe.

A) cruel

B) negatively curved

C) positively curved

D) flat

Why are the first photons the we detect from a time roughly 380,000 years after the Big Bang?

A) Because of the size of our telescopes; bigger telescopes could detect photons from earlier times.

B) At the start of the Big Bang, everything existed in the form of matter and anti-matter, which didn't annihilate and create energy until this time.

C) Before this time, all of the photons were absorbed by matter as part of the process of building the first stars.

D) Before this time, free electrons absorbed and scattered any photons, preventing them from moving through the universe.

Equation Sheet

Some useful numbers:

Radius	Distance
Moon = 1.7×10^6 m	Earth-Moon = 3.8×10^8 m
Earth = 6.4×10^6 m	Sun-Earth = 1.5×10^{11} m
Sun = 7.0×10^8 m	Sun-Alpha Centauri = 4.1×10^{16} m

1 light-year = 9.5×10^{15} m

1 parsec = 3.26 light-years = 3.086×10^{16} m

Parallax formula: $d = 1/p$ for d in pc, p in arcseconds

Small angle formula $S = \dfrac{\alpha \cdot d}{206265}$ for S, d in meters and α in arcseconds

Schwarzschild radius = 3 km (M/M_{Sun})

Hubble law $v = H_0 d$ where H_0 = 71 km/s/Mpc

$$\frac{\text{Flux}_A}{\text{Flux}_B} = \frac{\text{Luminosity}_A}{\text{Luminosity}_B}\left(\frac{\text{Distance}_B}{\text{Distance}_A}\right)^2$$

$$\frac{L_A}{L_B} = \frac{R_A^2 T_A^4}{R_B^2 T_B^4}$$