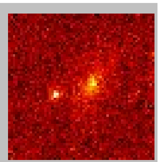
A supernova exploded in a distant galaxy. A feature in that galaxy's spectrum that normally appears at 4000Å was observed at 7440Å. What is the ratio of the size of the Universe today to that when the supernova exploded?



- A Size/Size today = 1/1+z. If z=the redshift, then z=3440A. Thus, the ratio of size/size today = 1/(1+3440) =.0003
- B 7440/4000 = 1 + z = Rnow/Rinitial
  1.86 = 1 + z
  z = .86, which is the ratio of the size of the Universe today to the size of the Universe when the supernova exploded.
- C 4000A/ (4000A + 7440A)= .35= 35/100
- D obs- emit/ emit = 7440a - 4000/ 7440 = .46 = 1960 mega parsecs 1960 to 1
- E assuming no redshift as a result of the doppler effect... 7440A/4000A=size now/ size then 1.86=size now/size then

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Expanding Universe Equation: $z = \frac{d}{c\, t_H}$

- c speed of light (we know this!)
- t_H current expansion timescale (the Hubble Time); we've measured this, and know it to about 5% now.
- z measured redshift
- d distance, measured using something from the Cosmic Distance Ladder

"Lookback time" $\Delta t = d/c$ = light travel time from object

---

$$z = \frac{d}{c\, t_H}$$

d = initial distance to object (for small Δd, distance now, distance when light was emitted, and light travel distance are all very close).

This is proportional to the "size of the Universe" (e.g. the average distance between galaxies)

Cosmo. Redshift = Expansion factor $z = \frac{\Delta d}{d} = \frac{d_{Now} - d}{d}$

With a wee bit of algebra :

$$1 + z = \frac{\text{Size Now}}{\text{Size at Emission}} = \frac{\text{Size Now}}{\text{Size Then}}$$

$$\frac{1}{1+z} = \frac{\text{Size Then}}{\text{Size Now}}$$

Describing a Uniform Expansion: $z = \frac{d}{c\, t_H}$ $\frac{\Delta d}{d} = \frac{\Delta t}{t_H}$

- During a constant time interval, farther objects change their distance by more : ***Δd∝d***

$$\Delta d = \left(\frac{\Delta t}{t_H}\right) d$$

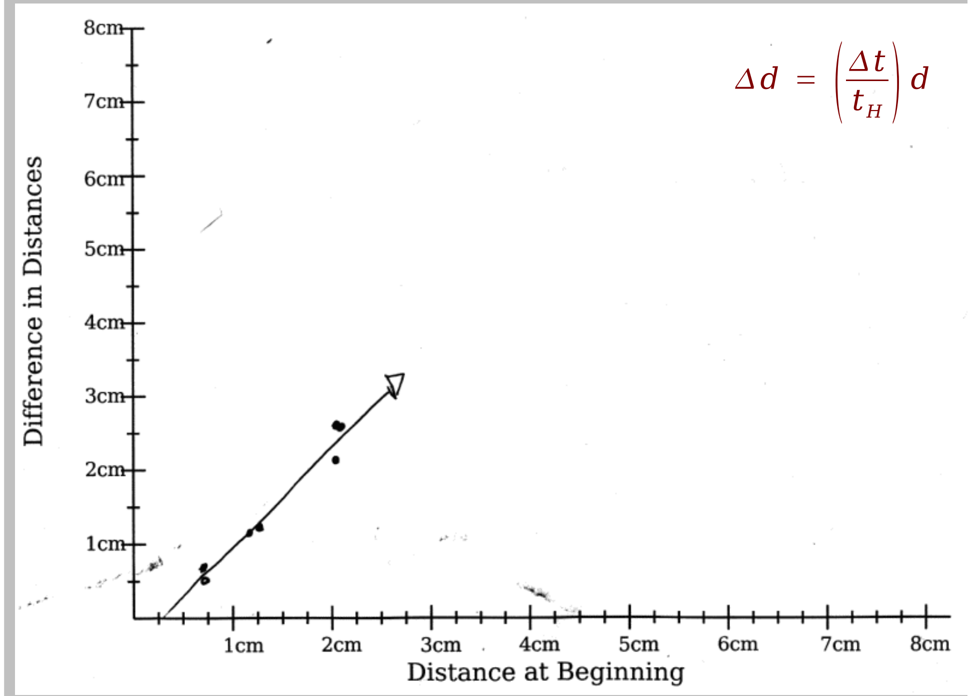
- At one moment in time, the rate of recession ($\Delta d/\Delta t$, or "speed" v) is is higher for more distant objects : ***Δd/Δt ∝ d***

$$\frac{\Delta d}{\Delta t} = \left(\frac{1}{t_H}\right) d$$

- The fractional change in distance to an object is proportional to the lookback time to that object : ***z=Δd/d ∝ Δt***

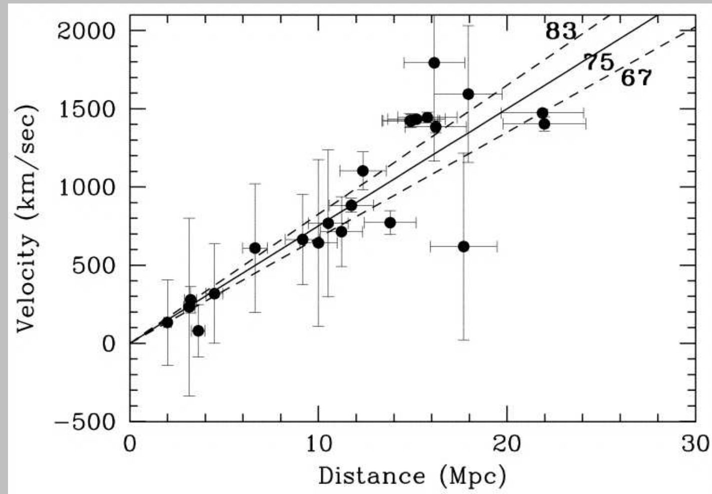
$$z = \left(\frac{1}{t_H}\right) \Delta t = \left(\frac{1}{t_H}\right)\left(\frac{d}{c}\right)$$

$$\Delta d = \left(\frac{\Delta t}{t_H}\right) d$$



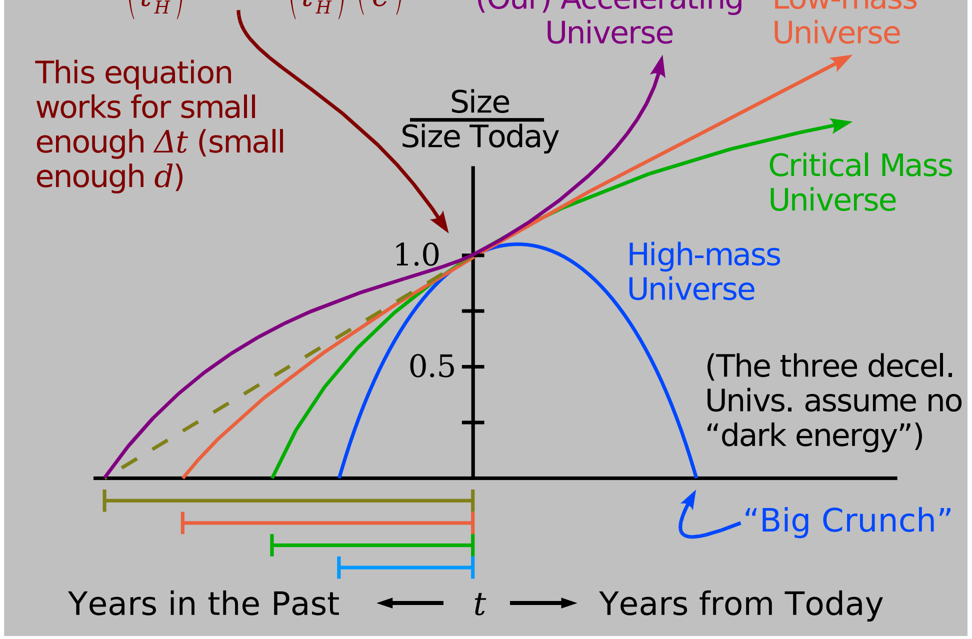
$$\frac{\Delta d}{\Delta t} = \left(\frac{1}{t_H}\right) d$$

$$\frac{\Delta d}{d}$$



d

$$z = \left(\frac{1}{t_H}\right) \Delta t = \left(\frac{1}{t_H}\right)\left(\frac{d}{c}\right)$$



Which equations work when????

$$\frac{\Delta d}{d} = \frac{\Delta t}{t_H}$$

Always true for a uniform expansion if d is initial distance, and Δd is change in distance during time Δt.

$$\frac{\Delta d}{\Delta t} = \left(\frac{1}{t_H}\right) d = H_0\, d$$

Always true as above... BUT we can't really measure d instantaneously! For the real Universe, this equation works for $(d/t_H) \ll c$, where we don't have to worry about interpreting d

$$z = \left(\frac{1}{t_H}\right) \Delta t = \left(\frac{1}{t_H}\right)\left(\frac{d}{c}\right)$$

Only true for Δt small enough that the expansion rate hasn't appreciably changed. Also, the d caveat applies as above. In practice, we need $z \ll 1$

$$z = \frac{\Delta d}{d}$$

Always true for cosmological expansion; Δd = change in size, d = size at emission.

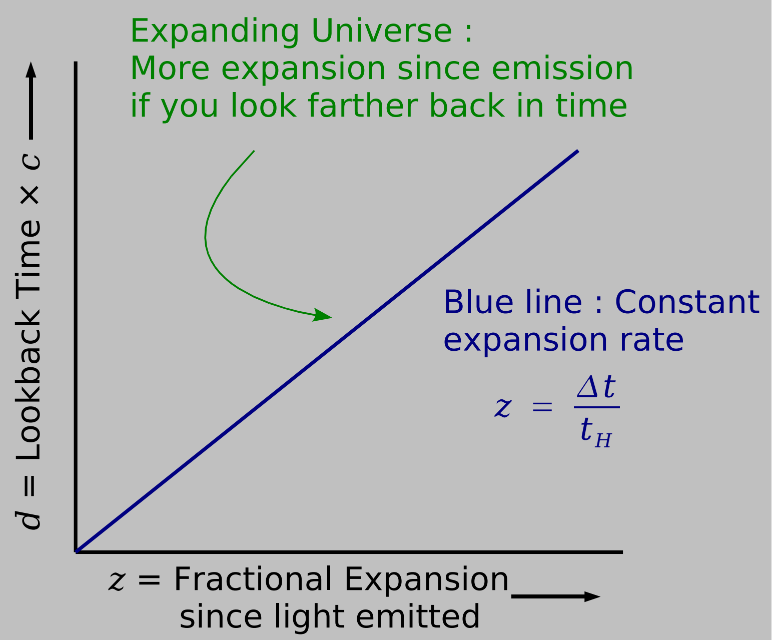
A galaxy at 40 Mpc (130 Mlyr) has *twice* the redshift of a galaxy at 20 Mpc (65 Mlyr). Which of the following statements is correct?

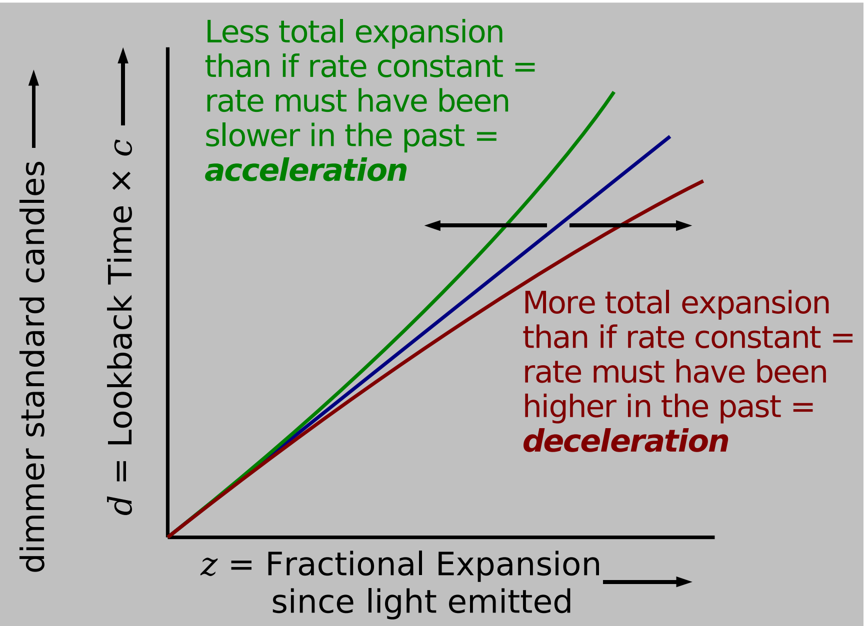
A The expansion of the Universe must have been twice as fast 130 million years ago as it was 65 million years ago, to explain the greater expansion seen from the farther galaxy.

B The expansion of the Universe didn't change appreciably between 130 million and 65 million years ago; we see more expansion because the light took longer to reach us.

C If observed, this would indicate that we do not appear to be at the center of a uniform expansion.

How do we measure acceleration or deceleration?





Dimmer-than-expected Supernovae ⇒ acceleration

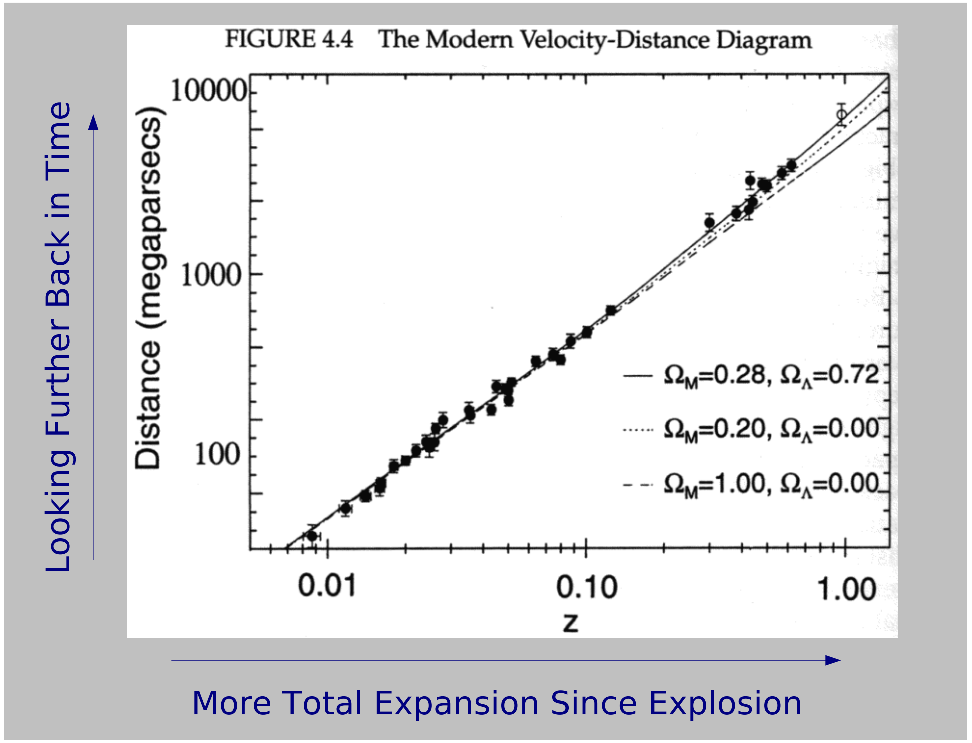
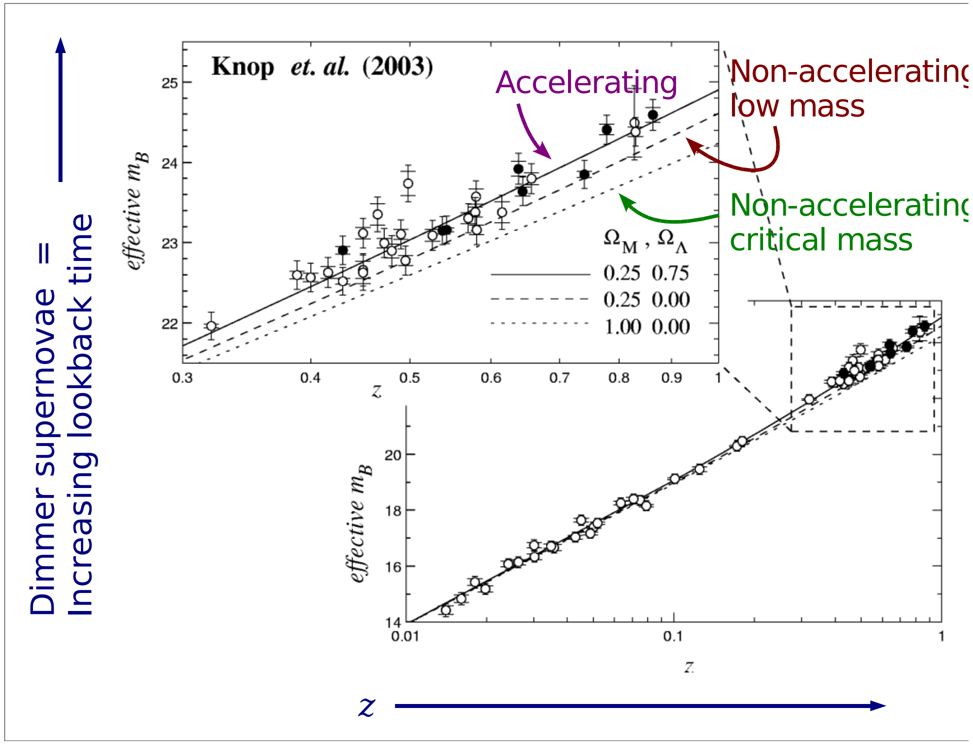
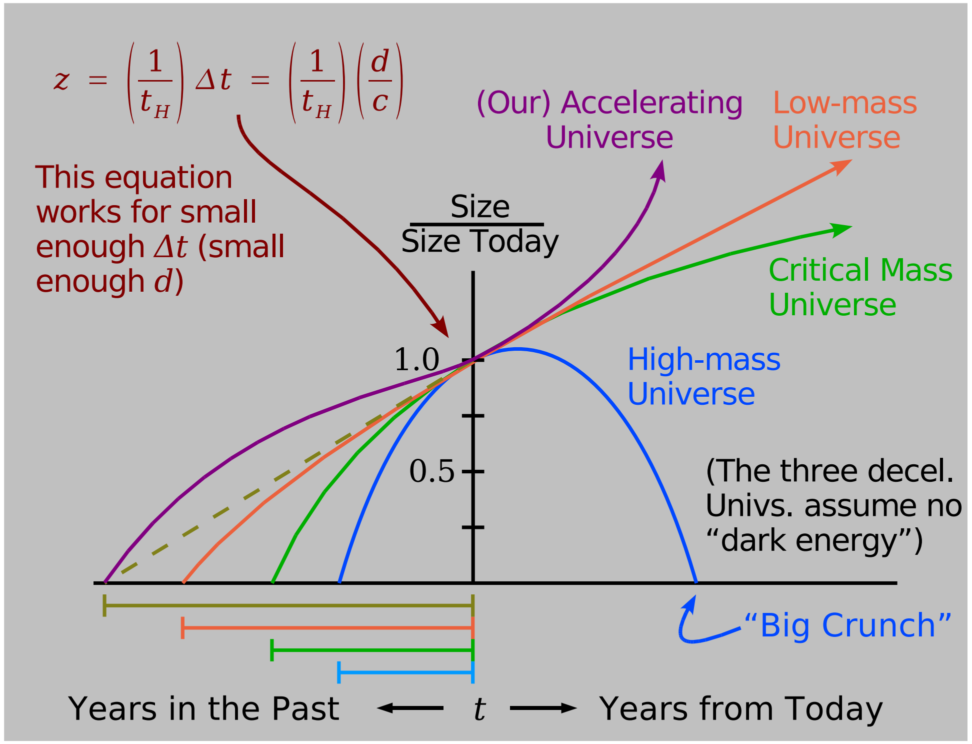


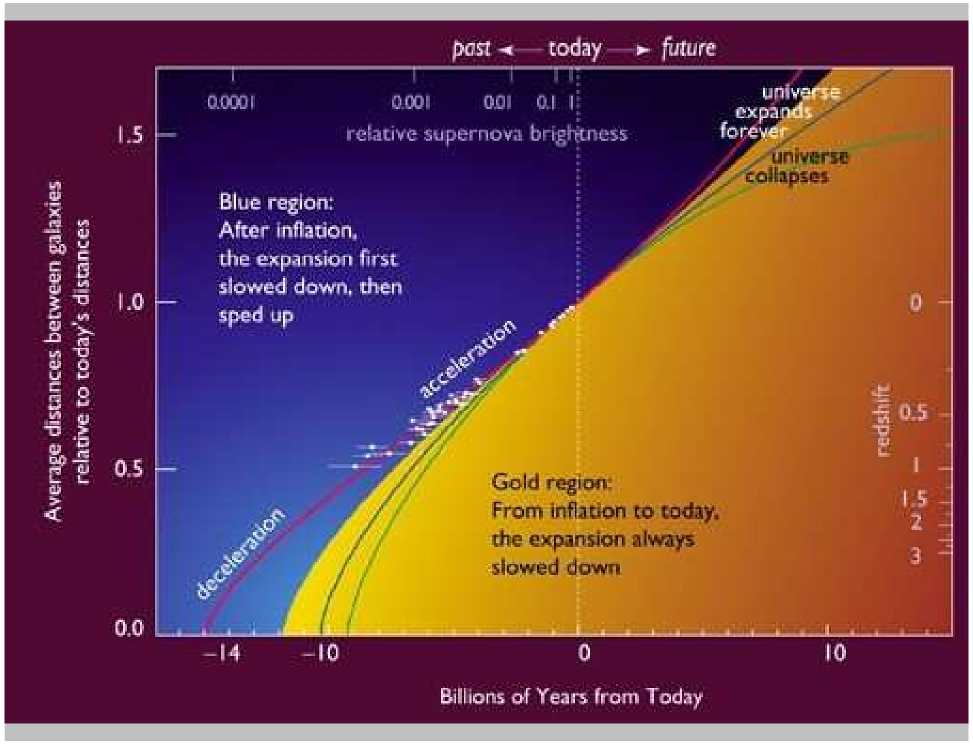
FIGURE 4.4 The Modern Velocity-Distance Diagram
Looking Further Back in Time
Distance (megaparsecs)
10000
1000
100
0.01
0.10
1.00
z
Ω_M=0.28, Ω_Λ=0.72
Ω_M=0.20, Ω_Λ=0.00
Ω_M=1.00, Ω_Λ=0.00
More Total Expansion Since Explosion



Dimmer supernovae = Increasing lookback time
Knop et. al. (2003)
Accelerating
Non-accelerating low mass
Non-accelerating critical mass
effective m_B
Ω_M , Ω_Λ
0.25 0.75
0.25 0.00
1.00 0.00
z



$z = \left(\frac{1}{t_H}\right)\Delta t = \left(\frac{1}{t_H}\right)\left(\frac{d}{c}\right)$
This equation works for small enough Δt (small enough d)
(Our) Accelerating Universe
Low-mass Universe
Critical Mass Universe
High-mass Universe
Size / Size Today
1.0
0.5
(The three decel. Univs. assume no "dark energy")
"Big Crunch"
Years in the Past ← t → Years from Today



past ← today → future
0.0001
0.001
0.01
0.1
1
relative supernova brightness
universe expands forever
universe collapses
Blue region: After inflation, the expansion first slowed down, then sped up
acceleration
deceleration
Gold region: From inflation to today, the expansion always slowed down
Average distances between galaxies relative to today's distances
redshift
Billions of Years from Today