

Pls hand in PS #6

frontiers & controversies 1950s

UNIVERSE EXPANDS

↓  
"Big Bang"

↓  
in the past: denser  
hotter

in the future: sparser  
cooler

things change in time  
→ implication  
"initial singularity"

↓  
past is different  
from present

↓  
"lookback time"

↓  
"Steady State"

new matter/energy  
is created to  
fill in the voids

past, future  
→ density same  
other char. same

→ eternal  
infinite

↓  
exists  
matter/energy  
creation

1960s:

\* discovery of "quasars"  
(accreting supermassive black holes)

HUGE energy source

high redshifts  $\rightarrow$  large distances

$\Rightarrow$  MANY MORE QUASARS  
IN THE PAST

$\Rightarrow$  a change in the  
composition of universe

\* "cosmic microwave background"

radiation generated when  
universe was

MUCH DENSER  
HOTTER  $\rightarrow 10^4$  °K  
SMOOTHER

strong support for B.B.

\*  $\frac{3}{4}$  H,  $\frac{1}{4}$  He  $\Rightarrow$  when early universe  
there was H fusion  $\rightarrow$  He

In first three minutes  
 $\frac{1}{4}$  of H fuses  $\rightarrow$  He  
afterwards no more (too cool)

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by now: galaxies evolve  
significantly

$\Rightarrow$  Big Bang

FABLE: demise of steady  
state

MORAL: || some science  
is anti-atheistic  
not anti-religious

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"Big Bang"

in past: denser, hotter,  
smoother

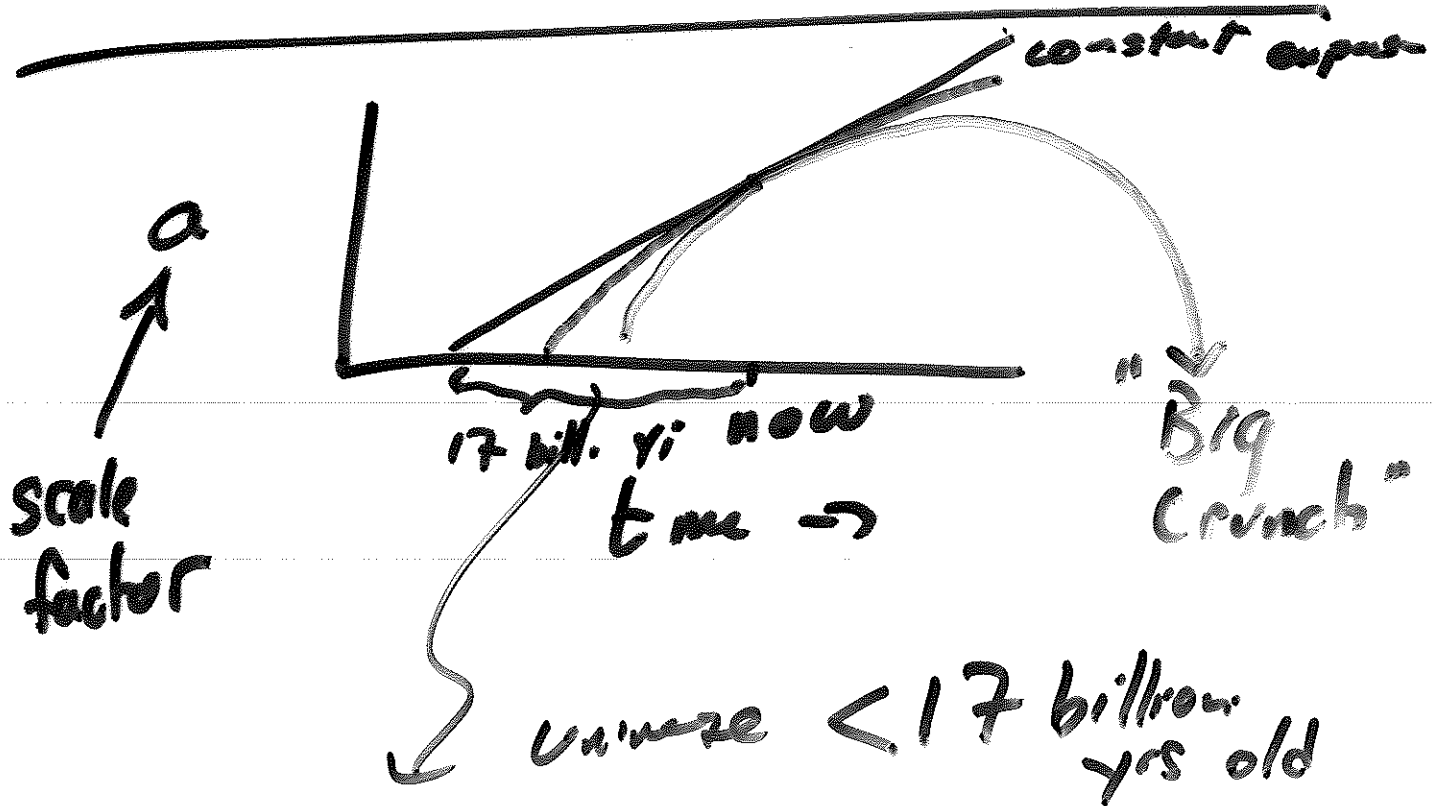
extrapolate to initial  
singularity

$$1 \text{ yr} = 3 \times 10^7 \text{ s}$$

age of Universe is

$$\frac{5 \times 10^{17}}{3 \times 10^7} = 1.7 \times 10^{10}$$

17 billion yrs



$$V = HD$$

↳ "Big Bang"

In a car driving 50 mph  
100 miles away from  
starting point.

How long have you been  
driving?

$$t = \frac{D}{V} = \frac{100}{50} = 2 \text{ hrs}$$

(provided speed is  
constant)

galaxy A is at distance  
D moving at velocity V

How long for a

$$t = D/V$$

$$V = \cancel{HD} \quad \left| \quad \frac{D}{V} = \frac{1}{H}$$
 →  $\frac{D}{V} = \frac{1}{H}$  measured!

Hubb Law

Age of Universe  
 $= 1/H$

$H = 70 \text{ km/s/Mpc}$

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$H = 70 \text{ km/s/Mpc} \left( \frac{\# \text{ of Mpc}}{1 \text{ km}} \right)$

$\rightarrow \frac{10^3}{10^6 \cdot 3 \times 10^{16}}$

$= \frac{1}{3} \times 10^{-19} = 3 \times 10^{-20}$

$H = 2 \times 10^1 \times 3 \times 10^{-20} = 20 \times 10^{-19} = 2 \times 10^{-18} \text{ 1/s}$

Open Yale courses

$\frac{1}{H} = \frac{1}{2 \times 10^{-18}} = \frac{1}{2} \times 10^{18} = 5 \times 10^{17} \text{ s}$



$$V_{esc} = \sqrt{\frac{2GM}{D}}$$

is  $V > V_{esc}$  ?

$$M = \text{density} \times \text{volume}$$

$$= \rho \frac{4}{3} \pi D^3$$

$$V = HD$$

$$\text{is } HD > \sqrt{\frac{2G}{D} \rho \frac{4}{3} \pi D^3} D^2$$

$$\text{is } H^2 D^2 > 2G \rho \frac{4}{3} \pi D^2 \quad ?$$

$$\text{is } \rho < \frac{3H^2}{8\pi G}$$

$$\Downarrow$$

$$\rho_{\text{CRIT}}$$

$$\text{if } \rho < \rho_{\text{CRIT}}$$

universe  
expands  
forever

$$\text{if } \rho > \rho_{\text{CRIT}}$$

universe  
recollapses

$$\frac{3 \cdot (2 \cdot 10^{-18})^2}{8\pi \cdot 7 \cdot 10^{22}}$$

$$= 6 \times 10^{-27} \text{ kg/m}^3$$