Please hand in PS #6

Planck & Compton: 1950s

Universe expands

"Big Bang"

in the past: denser, hotter

"Steady State"
new matter/energy is created to fill in the voids

in the future: sparser, cooler

past future

→ density same

→ eternal

infinite

Things change in time

implication

"initial singularity"

past is different

from future

→ exists

water/energy creation

"lookback time"
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 $\Rightarrow$ hotter $\rightarrow$ $10^{-4}$K
  Smoother support for B.B.

* $3/4 H$, $1/4 He \Rightarrow$ There was H from early universe $\rightarrow$ He
In first three minutes
1/4 of H fuses \( \rightarrow \) He
afterwards no more (too cool)

by now: galaxies evolve
Sun, Milky Way

\( \Rightarrow \) Big Bang

FABLE: demise of Sun, Skye

MORAL: some scare is anti-agnostic
not anti-religious

"Big Bang"

in past: denser, hotter, smoother
extrapolate to initial singularity
1 yr = 3 × 10^3 s

age of Universe is

\[
\frac{5 \times 10^{17}}{3 \times 10^9} = 1.7 \times 10^{10}
\]

17 billion yrs

scale factor

universe < 17 billion yrs old

"Big Crunch"
\[ V = \frac{HD}{\text{"Big Bang"}} \]

In a car driving 50 mph, 100 miles away from a study point, how long have you been driving?

\[ t = \frac{D}{v} = \frac{100}{50} = 2 \text{ hr} \]

(provided speed is constant)

Galaxy A is at distance \( D \) moving at velocity \( V \) going for \( t = \frac{D}{V} \)
\[ V = HD \]

\[ \frac{D}{V} = \frac{1}{H} \quad \text{measured!} \]

**Age of Universe**

\[ \frac{1}{H} \]

\[ H = 70 \text{ km/s/Mpc} \]

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

\[ \frac{10^3}{10^6 \times 3 \times 10^{16}} \]

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

\[ H = 2 \times 10^1 \times 3 \times 10^{-20} = 20 \times 10^{-19} \]

\[ \frac{2 \times 10^{-18}}{2} = \frac{1}{2} \times 10^9 = 5 \times 10^8 \]
\[ V_{\text{esc}} = \sqrt{\frac{2GM}{D}} \]

Is \( V > V_{\text{esc}} \) ?

\[ M = \text{dust} \times \text{volume} = 9 \frac{4}{3} \pi D^3 \]

Is \( HD > \sqrt{\frac{2G}{9} \frac{4}{3} \pi D^2} \)?
\[ H^2 P^2 > 2G \rho \frac{4}{3} \pi P^2 \]

\[ \rho < \frac{3H^2}{8\pi G} \]

\[ \downarrow \]

\[ \rho_{\text{crit}} \]

\[ \text{if } \rho < \rho_{\text{crit}} \]

Universe expands forever

\[ \text{if } \rho > \rho_{\text{crit}} \]

Universe recollapses

\[ 3 \cdot (2 \times 10^{-8})^2 \]

\[ \frac{8\pi 7 \times 10^{-46}}{8\pi 7 \times 10^{-46}} \]

\[ = 6 \times 10^{-27} \text{ m}^3 \text{ kg}^{-1} \]