1) Title of this talk contains an <u>absurdity</u>.
IF "Universe" = all matter and radiation that exists, we cannot speak of its "origin".
Origin → description of its derivation from pre-existing conditions.
Then the pre-existing conditions become part of what we would have to describe the origin of!
A never-ending loop of "what was before that?"
Obviously I can't give, and you wouldn't listen to, a never-ending talk!

I will use "Universe" = "matter and radiation that we know of"
<u>"Origin"</u> → "History since last traumatic rearrangement"

2) What I am going to say is short-sighted and parochial!

1) History = 20 billion yrs (approx.) Obviously will leave most of it out! Indeed really only describing the first few minutes!

2) Worse than that. I strongly believe that we always have a naïve and myopic view of the "Universe" because we are limited in how much of it we can understand due to our limited means of interacting with it. Throughout <u>our</u> recent history, the "Universe" has meant a whole sequence of steadily larger systems.

7● Slide - "Ages of Universe"

<u>1658</u> Archbishop Ussher of Armagh. Biblical chronology → Universe created on Sunday, 23rd Oct., 4004 B.C.

<u>1870</u> Lord Kelvin ~ 40 million yr age of Solar System, assuming Sun radiates by releasing gravit! pot! energy thru collapse.

<u>1930's</u> Early radioactive dating of Earth rocks → 2 billion yrs. First estimates of expansion time of galaxies → same.

<u>1972</u>   Most recent revision of expansion time → 20 billion yrs !
I think this indicates evolution of our concepts of Universe, based
in part on evolution of our Technology. If so, then what I say now
is best we can do given our <u>present limitations</u> : unless you believe
that now is the Golden Age of Final Insight then you must
believe that my lecture tonight is short-sighted and parochial.

That's <u>easy</u> — the hard part is to spot <u>how</u>, and <u>where</u>. And that
is what current research is about. I'll indicate possibilities based
on some of our thinking in the Astronomy Group here at Queen's.

3) What do we mean by the "Universe"?

3● Herschel (1738-1822). Famous because Discovered Uranus (1781)
9● Built huge Telescopes.
10● Surveyed stars (BRIGHTNESS ≡ NEARNESS)
11● Counted M.Way stars.

→ <u>Flattened disc</u>   — Concentration to M.Way.   ● 11A
   <u>Finite</u>   — "ran out" of faint stars. ● 11B
                                                  ● 11C

Hence "Universe" = star lens centred on Sun.

1920s   Shapley ⎤   "Foggy patches" - nebulae. among H's *S
        Hubble ⎥
        Humason ⎦ 12● → Resolved into stars by Mt.Wilson 100"
                 13-15●●●
         M31   BRIGHTNESS ≡ NEARNESS → <u>distant</u>
        +stars
                 16● "galaxies".   Ours = <u>one</u> of thousands.
                 -19   " Local Group" US + M31, etc
                 20● 200-inch
1950s   Sandage ⎤   Ours = one of <u>billions</u>
        deVaucouleurs⎥
        Zwicky ⎥
        Abell   ⎦   ● BRIGHTNESS ≡ NEARNESS → distances up
        gals   to billions of light-years.

● ~~Local Group~~

21,22● Clusters . — Basic Building Blocks of Universe.
100's of galaxies ~ regions 10 millim l.y. across .

23,24● Brightest galaxies in ^{rich} clusters v.similar. <u>GIANT galaxies.</u>
Good "standard candles", i.e. can apply BRIGHTNESS = NEARNESS!

25-28● Red Shift vs. Estimated Distance → [<u>Linear expansion.</u>]

4) Isotropy, Linearity of Flow. 29●
"Hubble flow' is cold, essentially isotropic. [<u>No edge in sight.</u>]
→ Extrapolate backwards. ∴ velocity ∝ distance → UNIQUE Time
when all matter now in clusters was once
in one place.

5) Uniqueness, Slowdown.
Uniqueness in space. Not of <u>us</u>. [Where were <u>we</u> at the beginning.]

Redshifts only → relative velocities. Do not
mean we are at.

Gravity must slow down expansion. So: origin of the expansion
must be at [a) unknown place
b) time < "Hubble Time".]

Would like to establish [<u>place</u>
<u>time</u>
<u>mechanism for expansion</u>]

Naive mechanism – (theory)

All matter in "one place" → density huge, as in unstable nucleus.

30 ● Some instability (physics inextrapolable!) → explosion
   → fastest travel furthest
   → coalesce → us, expanding

"BIG BANG" model.

$$\rho_m \sim 1/R^3 \qquad p_r = \tfrac{1}{3}\epsilon_r \qquad \epsilon_r = \rho_r c^2 \qquad d(\epsilon_r V) = -p_r dV$$
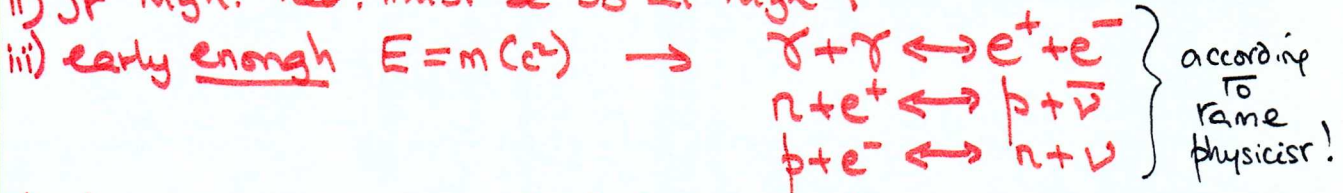
$$\epsilon_r dV + V d\epsilon_r = \tfrac{1}{3}\epsilon_r dV$$

$$\rho_r \sim 1/R^4 \qquad\qquad \frac{d\epsilon_r}{\epsilon_r} = -\frac{4}{3}\frac{dV}{V} \to \epsilon_r \propto 1/R^4$$

$$\therefore \rho_r \;\underline{must}\; > \rho_m \;\underline{initially}!$$

Test#1 i) ρ_m high. Rad^n must be BB. (Planckian)
   ii) ρ_r high. Rad^n must be BB at high T
   iii) early enough $E = m(c^2)$ →

$$\gamma + \gamma \leftrightarrow e^+ + e^-$$
$$n + e^+ \leftrightarrow p + \bar{\nu}$$
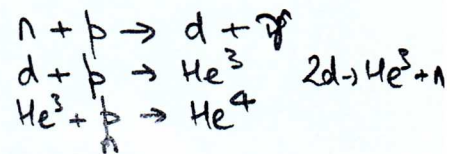$$p + e^- \leftrightarrow n + \nu$$

} according to same physicist!

All particles available. Statistical equilibrium.

Hence $\dfrac{[n]}{[p]} = \exp-\left[\dfrac{\Delta E}{kT}\right] = \exp\dfrac{-\Delta m c^2}{kT}$ $(\Delta m = m_n - m_p)$
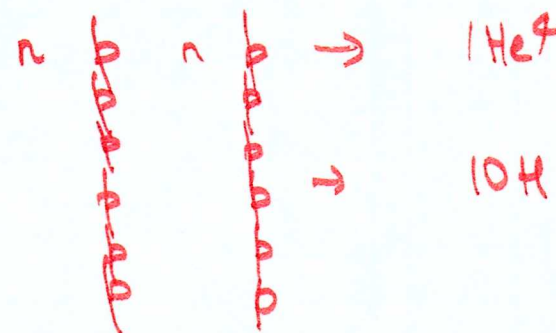
But equilibrium "frozen" at $T \sim 10^{10}$ ($\sim$1 sec) when $\bar{E}_\gamma < m_0(e^+, e^-)$

$\therefore$ can calculate $\dfrac{[n]}{[p]}$ at $t \sim$ 1 sec $\underline{regardless\ of\ start} = 1/6$

$T = 10^{10}$ to $T = 10^7$ fusion can occur.

$$n + p \to d + \gamma$$
$$d + p \to He^3 \qquad 2d \to He^3 + n$$
$$He^3 + p \to He^4$$

Test#2   n p n p → 1 He^4

    → 10 H

$$\boxed{\begin{aligned} \#\frac{He^4}{H} &\sim \frac{1}{10} \qquad \underline{expected}! \\[4pt] \frac{mass\ He^4}{total} &\sim \frac{4}{14} \sim .3 \end{aligned}}$$

Note: He^4 + h → Li^5 ...

Look at radiation now
Look at matter now
GLOBALLY, not LOCALLY

7. Tests of Big Bang. — Did it really happen?

Test 1) Black Body radiation — isotropic.

31
82 ● Penzias and Wilson discovered by accident in 1965

Now have confirmations of $\overset{33}{\underset{34}{●●}}$ 1) BB
2) Isotropy
3) Temperature.

→ There was once a dense hot phase of all Universe, unless
you can come up with an alternative explanation of this rad^n.

35 ● Test
2) Element abundances.

i) General decline with Z → build-up from light elements.

ii) He → C "gap" $3He^4 \to C^{12}$
$2He^4 \to Be^8 \to 2He^4$
$He^4 + H \to Li^5 \to He^4 + H$

iii) Fe^{56} "peak" Fe^{56} most stable grouping of nucleons.   35A S/NOVA ●

All consistent with build-up.   Time scale ?

Masses > He would need ~ 20 billion yrs to build up by known
processes in stars.

He would need ~200 billion yrs.
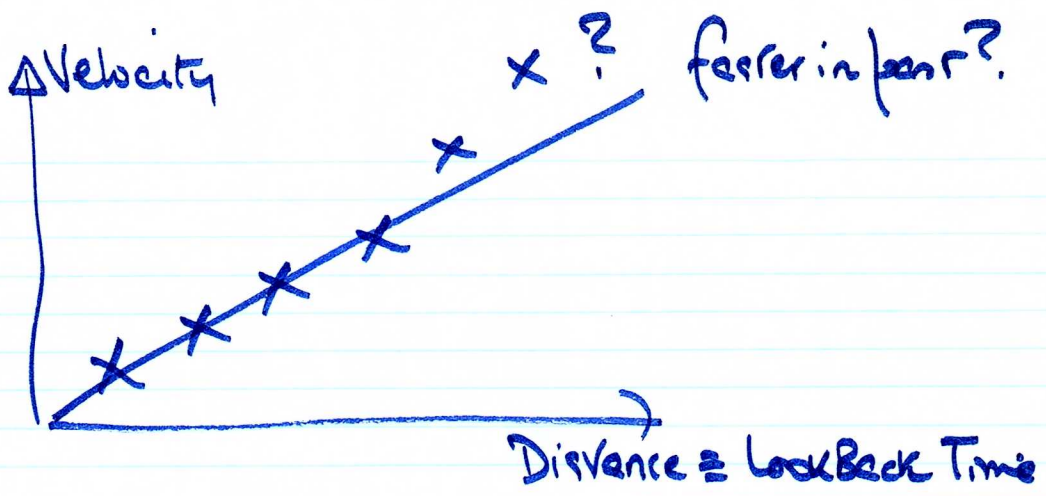
∴ if time must be < 20 billion, Helium must be primeval ✓

36 ●

Oldest * clusters (redgiants, etc.) → globulars.

HR diagram turn-off ages.   ~ 12-15 billion yrs.

Surfaces of MS stars only 0.01% heavies (fossil abundance)
But ~ 10% He by #! ✓   Also global — other galaxies 37 38 ●●

STRONG EVIDENCE TO SUPPORT BIG BANG

8) Slowdown

Slides 39 40 41

Velocity vs. Distance ≅ LookBack Time. x ? faster in past?

Ans. probably. But problem with galaxy evolution. LookBackTime ≅ Stellar evolution time for stars contributing much of galaxy light, so unfair to assume Brightness = Nearness? Check. Colors of galaxies? Sunlike stars → red giants. So more distant galaxies (younger) should be bluer?

42● 43● Radio sources may help (galaxies out to $z = 0.75$ now!)

Critical Density ~ $\dfrac{3H_0^2 (now)}{8\pi G}$ ~ few $\times 10^{-30}$ gm/cc. (stops expansion)

Within a factor of $\frac{1}{10}$ of critical → $2 \times$ critical.

9) Parochiality. Black hole $E = h\nu = mc^2 = \dfrac{GMm}{R}$

i.e. $GM = Rc^2$

M = 1 gm	R = 7×10^{-29} cm	$\rho \sim 6 \times 10^{83}$ g/cc !!
M = Sun	R = 1.5 Km	$\rho \sim 1.5 \times 10^7$ g/cc.
M = galaxy	R = 2000 A.U.	$\rho \sim 4 \times 10^{-6}$ g/cc.
M ~ "TheU."	R = 20 bill. L.Y.	$\rho \sim 4 \times 10^{-30} \sim \rho_{crit}$.

Are we **IN** a Black Hole?
Could there be other Black Holes OUT THERE – other "Universes"?