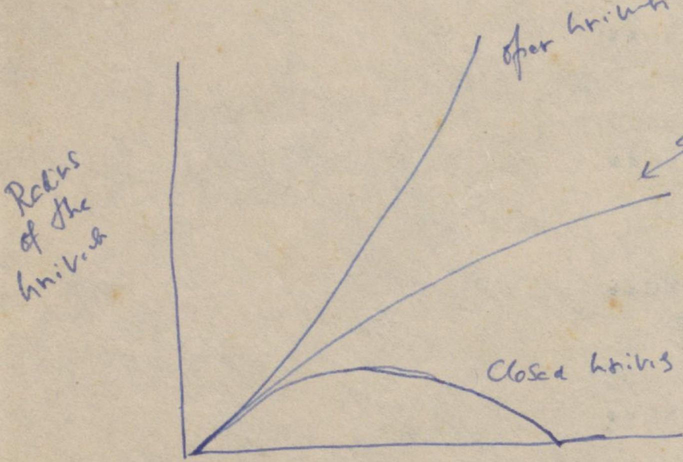
SKY AND TELESCOPE
JAN 1979

The ultimate fate of the Universe
(Jamal Islam. Cambridge University)



Stars after explosion → White Dwarf 7.5 $M_\odot$
→ Neutron star ~2-4 $M_\odot$?
→ Black hole. > 4 $M_\odot$?

At the rate at which stars normally radiate all of the stars in our galaxy will reach their final state after 10^{11} years — Black holes, neutron stars, White Dwarfs and other smaller bodies — planets.

Gravitational force will bind them together but no light or e.m. radiation of any kind.

— pitch black sky —

Some stars may leave the galaxy in a collision — what is left remaining will lead to the formation of a Giant galactic black hole. — 3×10^{9} kms radius

— few light hours —

These will tend to congregate —
Some galaxies encounter — Some escape —
Eventually the remaining galaxies will fall together
and merge into a super galactic black hole
10 - 1000 times large than the galactic b.h.

In about 10^{27} years the universe will consist of
galactic and super galactic black holes —
speeding away from each other — while
stray neutron stars, cold white dwarfs and
smaller black holes wander singly in the
vast space between them.

↓ The temperature of a super galactic black hole
~ $10^{-18°}$ K.
The Black Body Radiation (3°K Microwave Radiation)
would have cooled down to $10^{-18°}$ K.
after 10^{27} years
Life Time of ~~Super~~ a Galactic B.H ~ 10^{90} years.
Life Time of a Super Galactic B.H ~ 10^{100} years.
After this time the Super Galactic Black holes
would have disappeared leaving behind —
Neutron stars, black white dwarfs and planets
and smaller bits of matter that were
tossed out of the galaxies —
Temperature goes on drifting —

According to Q.M. all matter other than White Dwarf
neutron star, will have to decay through
Q.M. tunnelling —

10^{500} years - all matter will decay into Iron
which is the most stable.

White Dwarf and Neutron Star —

Freeman Dyson Calculations — Spontaneous
Q.M. tunnelling leading to compression of White Dwarf → Neutron Star

$10^{10^{77}}$ years — Dyson age

In a comparative time Neutron Star → Black Hole
— then B.H. evaporate by Hawking mechanism
→ only Elementary particles — protons, electrons, leptons.
Decay

Astronomical Revolution (1956 - 1981)

1956 Our knowledge of the Universe rested almost entirely on observations made with 100" optical telescope on Mount Wilson and 200" telescope at Palomar –

Although 2000 Radio sources had been catalogued, few had been identified with optical objects.

1958 Solvay Conference – { "Structure and Evolution of the Universe"

23 nebulosities in local galaxy
(3 S.N remnants inclusive)
23 Extragalactic objects – 16 normal + 7 abnormal.
headed by the radio source in Cygnus –
Only Victor Ambartsumian believed in Nuclear Explosion of the galaxy.

1960 Minkowski – High Red Shift object in Bootes
4500 million l.y.

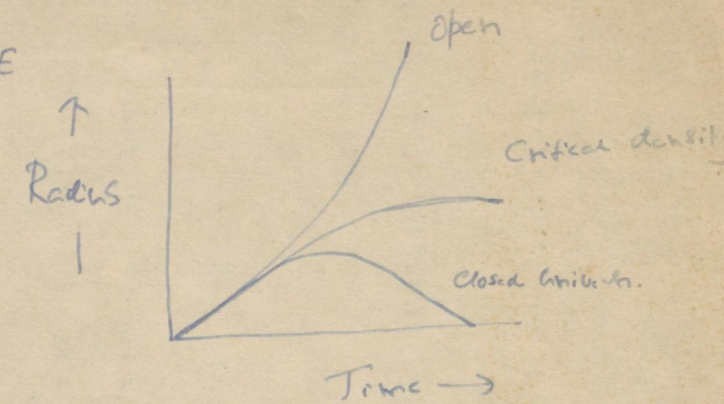
December 1960 – Sandage announced of another radio source of smaller diameter with 16th. magnitude 'blue' star

→ Quasars.

1967-68 Pulsars.

Microwave Radiation

ULTIMATE FATE OF THE UNIVERSE



According to present rate of radiation of stars in the Galaxy —

All stars will reach their final state in ~ 10^{11} years

→ White Dwarfs. (mass ~1.5 $M_\odot$)
Neutron Stars (mass > 2-4 $M_\odot$) ?
Black holes > 4 $M_\odot$?

The sky will be pitch black without any twinkle.

Some stars may leave the galaxy due to collissions.

The remaining will congregate and lead to the formation of a <u>Galactic Black hole</u> <u>3×10⁹ kms radius</u> (few light-hours)

Eventually the galaxies get together and merge into <u>Super Galactic Black Hole</u> 10, to 1000 times the size of Galactic Black hole. — This happens in a time scale of <u>10^{27}</u> years.

Stray cool white Dwarfs, Neutron Stars and small Black holes etc. wander singly in the vast space in between the Super Galactic Black holes.

* According to Hawking – Applications of quantum mechanical tunnel effect (say) – Black holes radiate.
The temperature of a super galactic black hole $\sim 10^{-18}$ °K.

* The 3°K microwave radiation also cools down to below 10^{-18} °K in a time of $\sim 10^{27}$ years.

* Life time of galactic black hole $\sim 10^{90}$ years
Life time of super galactic B.H $\sim 10^{100}$ years.

* In time scales of this order super galactic B.H. radiate away leaving behind cool white dwarfs, neutron stars etc. – that straggled away. – Temperature of the universe goes on dropping towards absolute zero.

* Again quantum mechanical tunneling leads to compression of these left over objects –
White dwarf → Neutron stars
Neutron star – Black holes
Black holes → Fundamental particles radiation.

~~Time scale 10^{500} years.~~

Time scale $10^{10^{77}}$ years – Dyson age.

(* Other matter decay by radioactivity into iron in time scale of 10^{500} years)

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The Rarity of Proton Decay in terms of the existence of X-particle of mass ~ 10^{15} eV can be understood as follows

According to Heisenberg's principle of uncertainty, only if two quarks approach each other closer than ~~10^{-28}~~ 10^{-28} cms can there be an exchange of X-particle resulting in the transmutation of the quarks into a lepton and anti quark. The chance of two quarks approaching each other within 10^{-28} cms is like two bees colliding with each other when they are confined in space as large as the Solar System.

<u>Matter and Anti-matter mystery</u>

In the Lab matter is always created along with antimatter. ∴ we may safely assume that this is so in the Big Bang Creation.

If equal amount of matter and antimatter was so produced

Where has all antimatter gone?

- Separate - More galaxies of antimatter?

Proton decay — new explanation of this anomaly.

~~Proton Decay — positron~~

Proton — quark matter
→ positron = lepton of antimatter.

No distinction between quarks and leptons →
No distinction between matter and antimatter.

Calculations show that heated up quark-lepton transmutations
during the big bang could have yielded one excess proton for
every matched billion proton-antiproton pairs. As the
universe expanded and cooled the pairs committed suicide
leaving behind a billion γ-rays along with left over protons
This colossal bath of radiation still fills the universe
to-day — but degraded so much in energy that it is
detectable only as a feeble glow of heat radiation —
a fading remnant of the searing violence that marked
creation of the world. — The tiny residue of matter
that remained constitutes all the galaxies, all the stars
and planets — you and me.

Ultimate fate

The discovery of Proton Decay conjures up a vivid image
of the Cosmos's ultimate fate.
As protons die one by one, they cough up positrons
into electron infested universe. — Soon annihilated —
All physical structures are destroyed & vanish. Ultimately
leaving behind just a few γ-rays as testimony
to their erstwhile existence. — Some electrons and
positrons that may escape — to keep company with
Black holes.

Time and Distance ~~Scales~~ and Temperature Scales

In Astrophysics we generally deal with time scales of millions to billions of years and distances of similar light years.

In particle physics we go to the other extreme and deal with distances down to 10^{-13} cms (a fermi) and time scales of 10^{-23} seconds. All the excitement in particle physics has come about by being able to probe to distances of 10^{-15} cms — ~~it~~ by electrons, protons, neutrinos etc. — which have provided evidence for the structure of the so called fundamental particles — protons, neutrons etc.

In astrophysics we — with greater and greater confidence in the Big Bang origin of the universe it has become necessary to consider time scales of not only a few minutes of the zero of the Big Bang, but time intervals as short as 10^{-42} seconds of the zero. — this is necessary if we really want to understand how the ball of radiation got transformed into the matter — the stuff ~~it~~ which was all the galaxies are made — how the protons and neutrons arise from the radiation.

Another important parameter we have to consider is the temperature scale. The 3° universal microwave radiation of to-day had a temperature of 3000°K when it was 1000 times smaller — the distance between any pairs being less by (1000 times) passing through a radiation dominated era to matter dominated era -

- The age of pure radiation began only at the end of first few minutes - when the temperature had fallen below a few thousand million degrees.

At 3000°K - energy of photon ~ 0.26 eV.

To produce e^+, e^- ~ 0.5 MeV × 2 ≃ 1 MeV.

temperature necessary 6×10^{9} °K.

higher than any temperature that we encounter in to-day's universe. (even the centre of the sun has a temp 15×10^{6} °K.

μ^+, μ^- 105 MeV each.

Temperature 1.2×10^{12} °K.

$P, N, \bar{P}, \bar{N}$ .. 10^{13} °K.

If the universe in the first few minutes was really composed of precisely equal number of particles and anti-particles then by the time the temperature dropped below 10^{9}°K - nothing would be left but radiation - There is good evidence against this possibility - Excess of electrons over positrons and protons over antiprotons, neutrons over anti neutrons. -

~~As soon as we~~ [we] admit of an excess matter over antimatter in the first few minutes - this is when the importance of Proton Decay - the whole argument becomes important -

how does this excess occur?

$\cdot 01 = 1/100$

> ~~·001~~ Seconds — $T = 10^{11}\,°K$.

undifferentiated soup of matter and radiation
— perfect thermal equilibrium.
charge, baryon number, lepton number — small or zero
electrons, positrons, neutrinos, antineutrinos —
The universe is so dense that even ν's are in thermal
equilibrium. — Mean Density $\underline{3 \times 10^{9}\ gms/cc}$.

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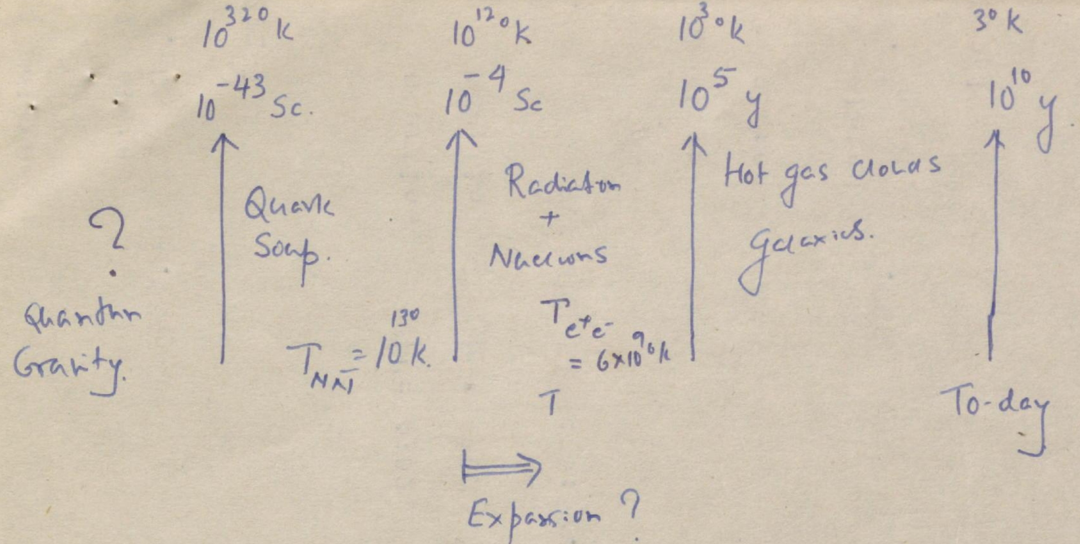


10^{-43} Sc – quarks packed together as tightly as quantum effects allow.

10^{5} y – Matter and Radiation parted Company –

10^{-4} Sc – density so high that the Separation between protons and Neutrons became Comparable to the Size of these particles.

∴ higher densities Can be thought of Only in the frame work of quark theories – An important aspect of Quark-quark force is that it becomes weaker at ~~Shorter~~ distances and asymptotically weaker at zero ~~Separation~~.

∴ at higher densities the "quark Soup" became a mixture of Separate non-interacting particles. & this case the temperature Can ~~still~~ go still higher towards the beginning of the Universe

Than other elementary particle theories not involving quarks. According to these – the temperature will not rise, but the number of types of elementary particles will increase.

In the quark model – how far can one go back?

According to General Relativity – "Singularity" in the solution of the cosmological equations – at $t=0$. (Zero of cosmic age)

But Quantum Effects do not allow the existence of a 'point like' singularity. (Uncertainty principle)

'quark' in the quark soup assumes fuzziness.

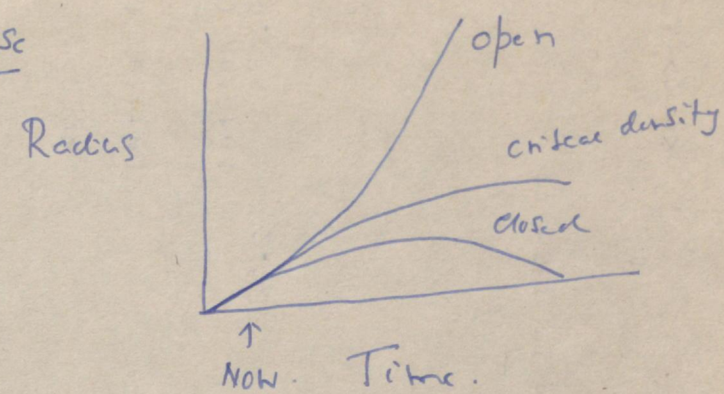
Quantum Mechanical size of the quark becomes important at the cosmic age of 10^{-43} seconds. (Temperature 10^{32} °K)

At the moment we cannot go beyond this limit. –

~~the~~ until we have a proper understanding of

<u>quantum nature of gravity</u>.

Towards the End of the Universe



Open Universe – Ever Expanding

10^9 years. Sun stops radiating

10^{11} y Stars stop radiating — pitch black sky.

10^{27} y Formation of Galactic Black holes. Stray White Dwarfs, Neutron Stars, planets

$T_{G.B.H} \sim 10^{90}$ years.

Super Galactic Black hole. of Temp $10^{-18°}$ K.

After 10^{27} years Cosmic Background Radiation also falls below $10^{-18°}$K.

$T_{Su.Gal.Black\ H} \sim 10^{100}$ years

Quantum [illegible] Conversion and Q-M tunnelling

10^{500} y → [illegible]

$10^{10^{77}}$ y – → Evaporation of B.H.

Dyson [illegible]

Closed Universe ⟶ Big Crunch.

(density > than critical density.)

	Temp.	Radius of Universe	Comments.
Time from [illegible]: 10^{10} years	3° K.	2×10^{10} ly.	– Life possible
60×10^{10} y	1.5° K	4×10^{10} ly	Maximum Expansion
Time from Crunch: 7×10^{7} y	300°K	2×10^{8} ly	Night as bright as day
7×10^{5} y	3000°K	2×10^{7} ly	Molecules and atoms dissociate.
3 weeks	10^{7}°K	6000	Stars and planets dissolve
3 minutes	10^{10}°K	6	Nuclei break up
0.1 Seconds	10^{11}°K	0.6	dense Soup of elementary particles.

Matter- Anti matter ~~anomaly~~ asymmetry

Baryon- photon ratio. —

$$\frac{\text{Cosmic Density of matter}}{\text{Cosmic Density of } 3^\circ K \text{ radiation}} \sim 10^{-9}$$

Baryon Conservation — universe starts out symmetrically.

No evidence for anti matter stars, galaxies.

Universe is dominated by particles compared to anti particles.

Solution to this puzzle lies in Cosmology - but in particle physics.

— unification of the three interactions — E-M, weak, strong.

presence of X-particles (10^{15} GeV mass)

possible only at temperature higher than $10^{32\circ}$ K. ~~[illegible]~~

Below $10^{28\circ}$K — No creation of X-particles —

are those produced will decay in their decay (less the symmetry breaking time scale

10^{-35} seconds of zero)

At time $T > 10^{-35}$ s. — the universe became asymmetric.

too hot to form protons and neutrons. only quarks [illegible] into

a baryon number. — few baryons over anti baryons

but this asymmetry at 10^{-4} [illegible].

~~[illegible]~~ Baryons and anti-baryons annihilate giving rise to the

photons. The remaining baryons became up the matter of

the universe.

The ratio of 10^{-9} [illegible] [illegible] the [illegible] [illegible]

$10^{-3} - 10^{-13}$ for the ~~[illegible]~~ [illegible] to photon ratio.

One go one step further and invoke Hawking's primordial
black holes - these black holes decay into X and anti X particles
when they decay they produce non-zero baryon number

~~An alternative path is that the primordial b.h. decay evaporate~~
~~into baryons and anti-baryons~~ but makes no

An alternative path is that the lighter stars are } cont. with
small black holes that evaporate into X-particles

Black holes — X-particles — quarks — baryons anti-baryons — leptons, antileptons

to dominate + baryons. — leptons