Particle Physics

- **Discharge of Electricity through gases (1900)**
  - Electron, Proton.
- **Blackbody Radiation.**
  - Quantum hypothesis
  - Photon
    - Photoelectric effect
    - Compton effect.
    - Raman effect.
- **Radioactivity**
  - Nucleus (1912)
  - Neutron (1932)
  - β-decay
  - Neutrino.
- **Cosmic Rays**
  - positron (1932)
  - Muon (1935)
  - Pion (1947)
  - K-meson
  - Λ^0
  - Hyperons ($\Sigma^{\pm}$, Ξ^-, Λ)
- **Accelerators** (1955)
  - Resonances
  - Ω^-
  - ψ/J
  - Υ
  - $W^{\pm}$
  - Z^0
  - Quarks

High Energy Physics.

Cosmic Rays

- Bremstrahlung
- Pair Production.
- Cascade development.
- Meson Decay
- Meson Production.
- Strange Particles - Strangness.
- τ - θ puzzle - Parity violation.
- Clusters, High P_t, Partial inelasticity

Accelerators

- Anti-Particles - $\bar{P}$, $\bar{N}$
- Partons
- Quark Structure
- Electro-weak Unification
- Neutral Currents
- Standard Model.

↓

Super Symmetry
SUSY GUTS

TOP Quark,
Higgs Boson.
New Quarks ?
New Leptons ?.
INO'S. → Zino, Wino, photino, Gravitino, ⋮

In the 1st. Second → the Universe is inflated to the Size of Solar System.

At 3 mins → the expanding Universe becomes a FUSION REACTOR - Synthesizing hydrogen, helium, Lithium nuclei from a hot dense Soup of elementary particles.

At 30,000 yrs → Cooled enough to allow Atoms to form.

~1 billion yrs → Atoms Clumping to form galaxies

Big Questions: Why is the Universe Lumpy?
How did galaxies form?
Are there other Planetary Systems?
How will the Universe end?

(5)

Exotic Environments of Neutron Stars, Black Holes, Accreting Binaries Active Galactic Nuclei

Supernova explosions of massive stars leave behind remnants which are either Neutron Stars or Black holes.

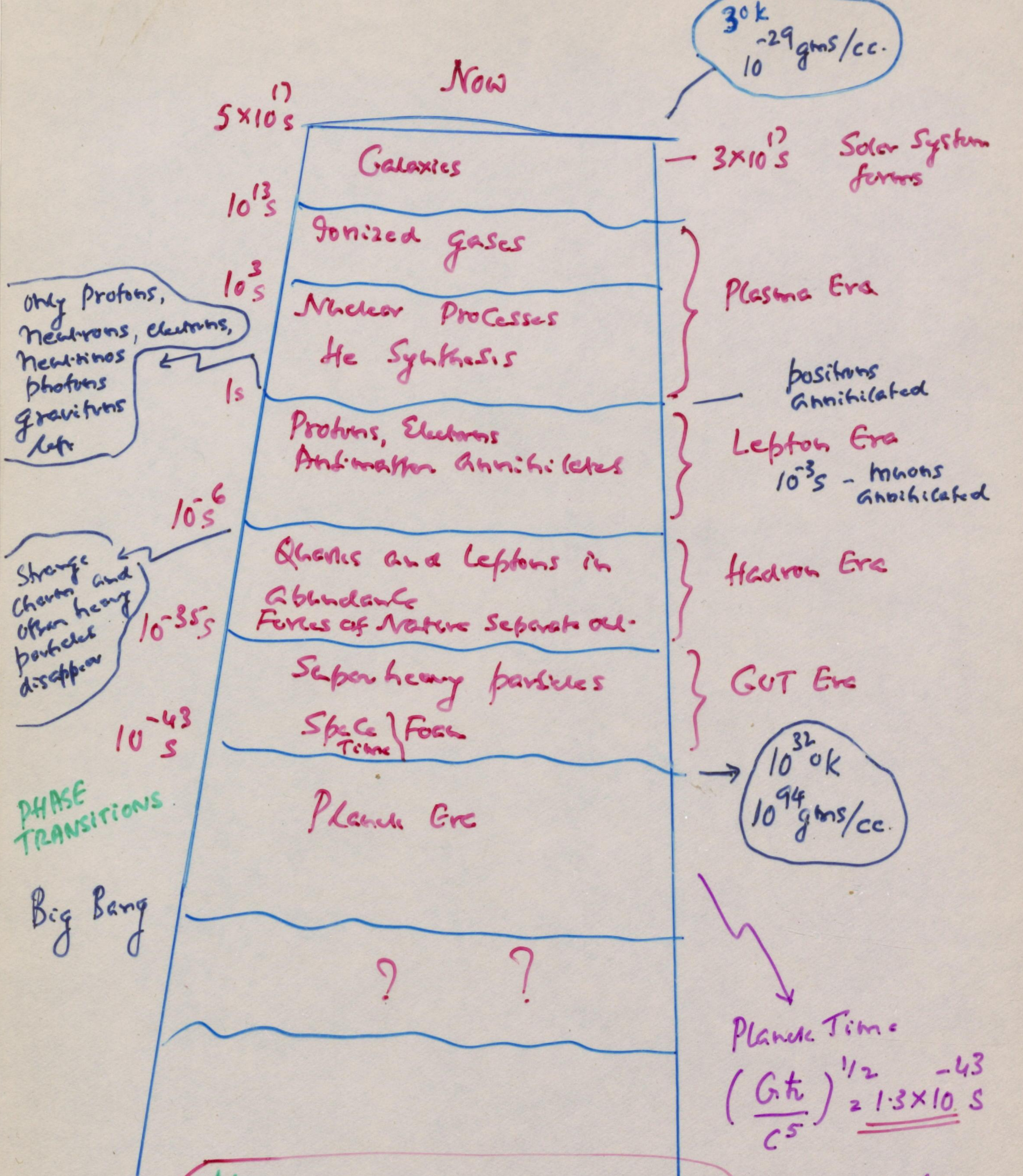
The Neutron Star: Size ~ 10 kms.
Density ~ 10^{14} gms/cc.
Magnetic field ~ 10^{12} gauss
Rate of rotation ~ milliseconds to tens of sc.

Sources of Radio, UV, x-ray, γ-ray, Tev, Pev radiations.
- Continuous and Burst Like. - rapid burster.

Black holes - accretion of matter leads to production of very high temperatures and emissions of x, γ, Tev, Pev, radiations.
Cyg x-1

Giant Black Holes ~ $10^6 M_\odot$ - at the Centres of AGN's - Sources of very high energy radiations - Most Powerful Sources like Quasars, Seyfert Galaxies, etc.
• Prospects in Tev Neutrino Astronomy.

Colliding Neutron Stars - Sources of γ-ray bursts. ?
matter-antimatter production and annihilation



Planck Time

$$\left(\frac{G\hbar}{c^5}\right)^{1/2} = 1.3\times10^{-43}\ S$$

HISTORY OF THE UNIVERSE

Planck Length.

$$\left(\frac{G\hbar}{c^3}\right)^{1/2} = 1.6\times10^{-33}\ \text{cms}$$

$$\left[10^{80}\ \text{Baryons} + 10^{89}\ \text{photons}\right]$$

$\frac{\text{Photon}}{\text{Baryons}} \sim 10^{9}$ (Why)

Anti-matter ??

Interior of Stars.

- The Core temperature of a Star depends on the nuclear fuel that is burning on the outside.
- Inside the Sun, where the fuel is still hydrogen the temperature is 1.3×10^7 °K.
- At these temperatures, the fusion reaction

$$4\,{}^1H \rightarrow {}^4He + 2e^+ + 2\nu + \text{Energy}$$

takes place. The positrons get annihilated. The neutrinos which escape provide the signature for the fusion reaction taking place in the interior.

In principle

$${}^4He + {}^4He \rightarrow {}^8B$$
$${}^4He + {}^1H \rightarrow \; ?$$

} Should take place. These are extremely unstable.

Fred Hoyle Conjectured the triple reaction

$${}^4He + {}^4He + {}^4He \longrightarrow {}^{12}C^*$$ – Excited State of Carbon.

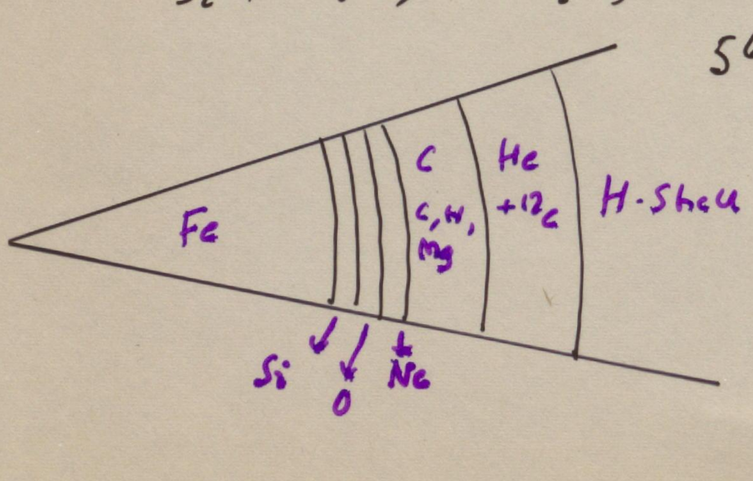
(Resonance σ necessary) * (established later in Lab Experiments)

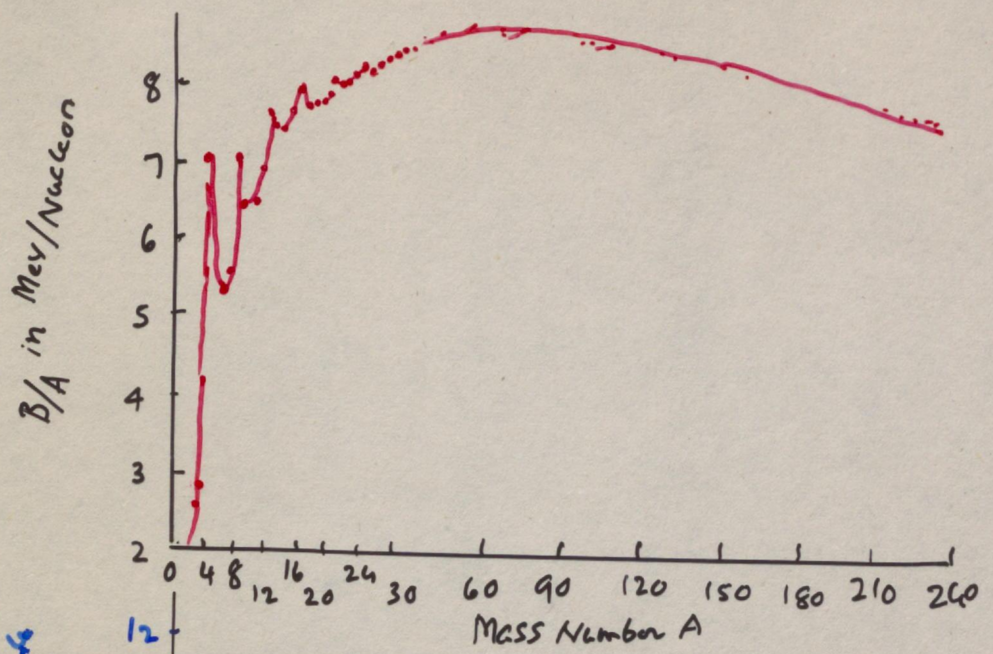
Successive Additions lead to

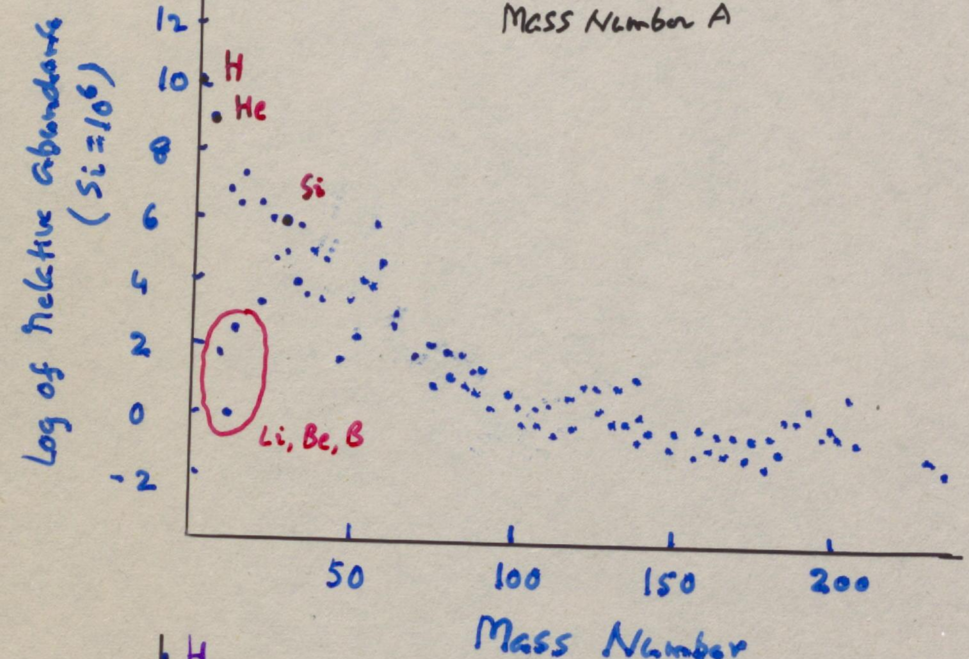
8×10^8 °K, 1.5×10^9 °K: ${}^{12}C + {}^4He \rightarrow {}^{16}O + \text{Energy}$, ${}^{20}Ne$, ${}^{24}Mg$, ${}^{28}Si$, ${}^{32}S$, ...

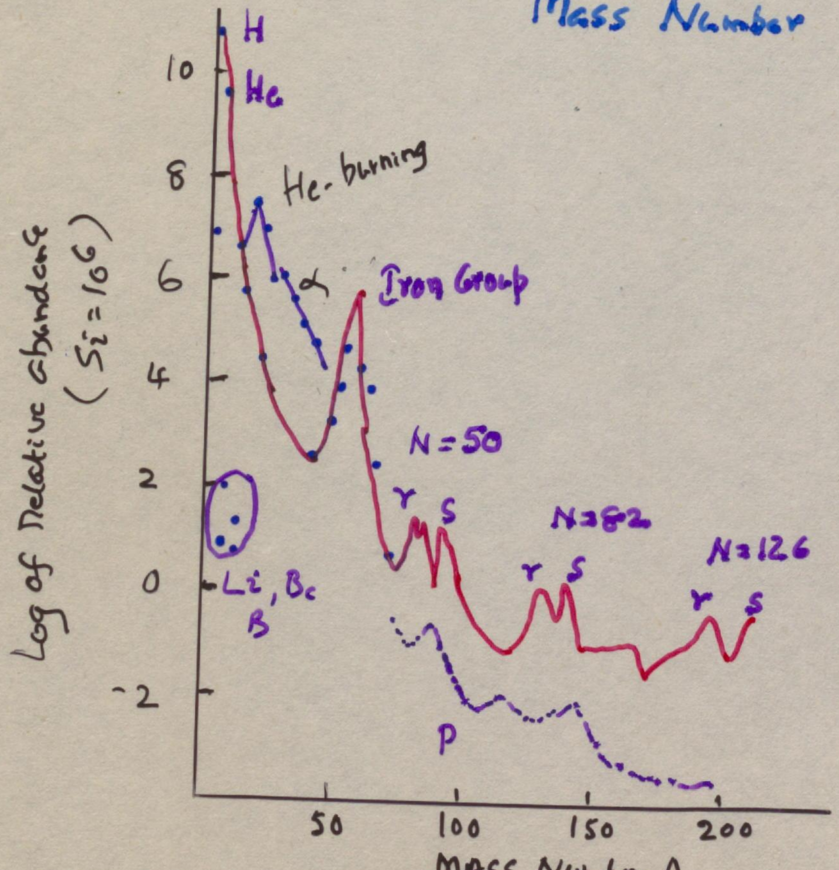
3×10^9 °K: ${}^{28}Si + {}^{28}Si \rightarrow {}^{56}Ni$; ${}^{56}Ni \longrightarrow {}^{56}Co + e^+ + \nu_e$

${}^{56}Co \longrightarrow {}^{56}Fe + e^+ + \nu_e$.









Universal Abundance of Elements.

Typical Values

$Si = 10^6$

$H = 3.18 \times 10^{10}$

$D = 5.2 \times 10^5$

$^4He = 2.21 \times 10^9$

$^3He = 3.7 \times 10^5$

$^7Li = 45.8$

$^8B = 0.81$

$^{12}C = 1.17 \times 10^7$

$^{16}O = 2.14 \times 10^7$

⋮

$^{32}S = 4.75 \times 10^5$

$^{63}Cu = 373$

⋮

$^{90}Zr = 14.4$

⋮

$^{90}Th = 0.058$

$^{92}U = 0.0199$

NATIONAL INSTITUTE OF ADVANCED STUDIES

Stellar Explosions - Supernovae -

INDIAN INSTITUTE OF SCIENCE CAMPUS
BANGALORE - 560 012, INDIA

Formation of heavier elements take place through neutron capture.

's' process - Slow Process - Neutrons captured at a rate slower than β-decay of neutrons. ∴ produce nuclei rich in neutrons.

'r' process - rapid process - β-decay faster than capture ∴ produce nuclei rich in protons.

'p' process - In the explosive phase the fast flux of photons, protons produce through collisions some nuclei

'x' process - { Unknown processes - that produce light nuclei deuterium, lithium, beryllium and boron. Some link these with Big Bang early phase.

Explosive Synthesis of Aluminium. - (Allende Meteorite) Anomalously rich in Aluminium.

$$^{24}Mg + N \rightarrow {}^{25}Mg$$
$$^{25}Mg + N \rightarrow {}^{26}Mg$$
$$^{26}Mg + P \rightarrow {}^{26}Al + N$$

} The Shock wave of SN heats temporarily the interstellar medium to a high temperature for this process to take place.

Fluctuation in density required for the formation of the Solar System could have taken place due to the shock waves generated by SN explosion of another star. Death of a star leads to Birth of another.

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The Early Universe

Time after Big Bang	Temperature of the Universe	Density of the Universe	Neutron / Proton	
3 mins 2 Sc.	10^9 °K (70 times Solar Temp)		14/86	e^+, e^- have mostly disappeared. Deuterium bottleneck still present
A little later.			13/87	D bottleneck removed. Tritium, ^3He, ^4He formed.
34 mins 40s.	3×10^8 °K.	9.9 gms/cc.		$e^+ e^-$ completely annihilated. Only 10^{-9} left as electrons to compensate the charge on protons. $\nu\bar{\nu}$ ~ 31%. photons ~ 69%
	22 to 28 % He. too hot for He atoms to form.			
700,000 yrs		Atoms form.		
10^{10} yr		Life Appear.		

The Steady State Universe

- Infinite Universe. Boundless
  No beginning. No end. No day of Creation. No Doomsday.
  (this applies to the Universe as a whole.
  The Earth the Solar System will perhaps vanish)
- The Universe has been expanding all through eternity. Will continue to expand for ever.
- But the total number of observable galaxies has not changed. Many have passed beyond the range of telescopes. They are replaced by new fresh galaxies formed from new matter continuously created.
- One atom per year in a large sized room.
  ↓
  → For the Universe ~~has~~ as a whole this translates to the creation of matter of 5000 suns per second!
- How is matter created?

Objections: The 3° radiation
The Helium Abundance.
Evolution of Radio Sources
⋮

The Inflationary Scenario.

According to current ideas of physics (Particle Physics, Relativity, Quantum Mechanics) there are two types Vacuum

1. True Vacuum: Empty space, empty of matter and empty of Energy

2. False Vacuum: Empty space, empty of matter, but not empty of energy.

... The Energy is not of the ordinary form such as due to electrical fields or gravitational field, but of a new kind of field.

Important characteristic of false vacuum is that according to the General Theory of Relativity, a region filled with energy like the false vacuum, must expand suddenly and explosively filling more and more of space with vacuum (false vacuum).

• To start with we have true vacuum without matter, without energy. But according to Quantum Mechanics even true vacuum is subject to fluctuations. The field that provides energy to the false vacuum is absent in true vacuum, but not completely.

At one moment, in a small region of true vacuum fluctuates into false vacuum — this region suddenly expands. This is the Big Bang Explosion.

- Exciting Science is always in the frontiers, and there are many, many frontiers where this is happening.

  Physics - Astronomy frontier is one such. - Characterized by High Science and High Technology.

- Physics in this Century has moved in the direction of the small - ultra small - Molecules - Atoms - Elementary Particles - Quarks and Leptons.

  and towards unification of forces.

- Astronomy has moved in the direction of larger distances, larger structures and towards recognition of totally unfamiliar and exotic environments in the Universe.

- There has been a symbiosis between Physics and Astronomy. Progress in one has depended and influenced the progress in the other.

- A recent realisation is that findings in the Microcosmos
  of elementary particles is very relevant to the
  very origin of the Macrocosmos - the Universe, and
  the very early Universe - the first moments after
  Creation is the highest energy accelerator laboratory
  that can ever be created and the remnants of the
  happenings in those early moments, hold the key to
  much of high energy physics.

- It is an area in which India is well placed for making significant contributions.

Scale Factor	Time From Big Bang	Temp of Radiation	Matter Density	EVENT.
1	2×10^{10} yrs	3°K	$\sim 10^{-30}$ $g\,cm^{-3}$	Present Universe
$1/1500$	10^{7} yrs	4000°K	$\sim 10^{-20}$	Neutral Hydrogen in the Universe is ionised
$1/1000$ - $1/10{,}000$	$2\text{-}20 \times 10^{6}$ yrs	3000 - 30,000°K }	10^{-21} 10^{-18} }	Equal amount of Matter and Radiation; At earlier times the Universe is radiation dominated.
$1/10^{9}$	10 mins	3×10^{9} °K	10^{-3}	Nuclei of atoms dissociate
$1/3 \cdot 10^{9}$	1 min.	10^{10} °K	3×10^{-2}	Electron - Positron pairs are Created from Thermal Background.
$1/10^{13}$	10^{-5} seconds	10^{13} °K	10^{9}	Proton-Anti Proton, baryon-anti-baryon production from Thermal Background Radiation.

Present Size of the Universe $\sim 10^{28}$ cms

$e^{+}e^{-}$ threshold (0.51 Mev) $\sim 6 \times 10^{9}$ °K

$p\bar{p}$ " (1 Gev) $\sim 1.1 \times 10^{13}$ °K

Pion Production $\sim 1.5 \times 10^{12}$ °K

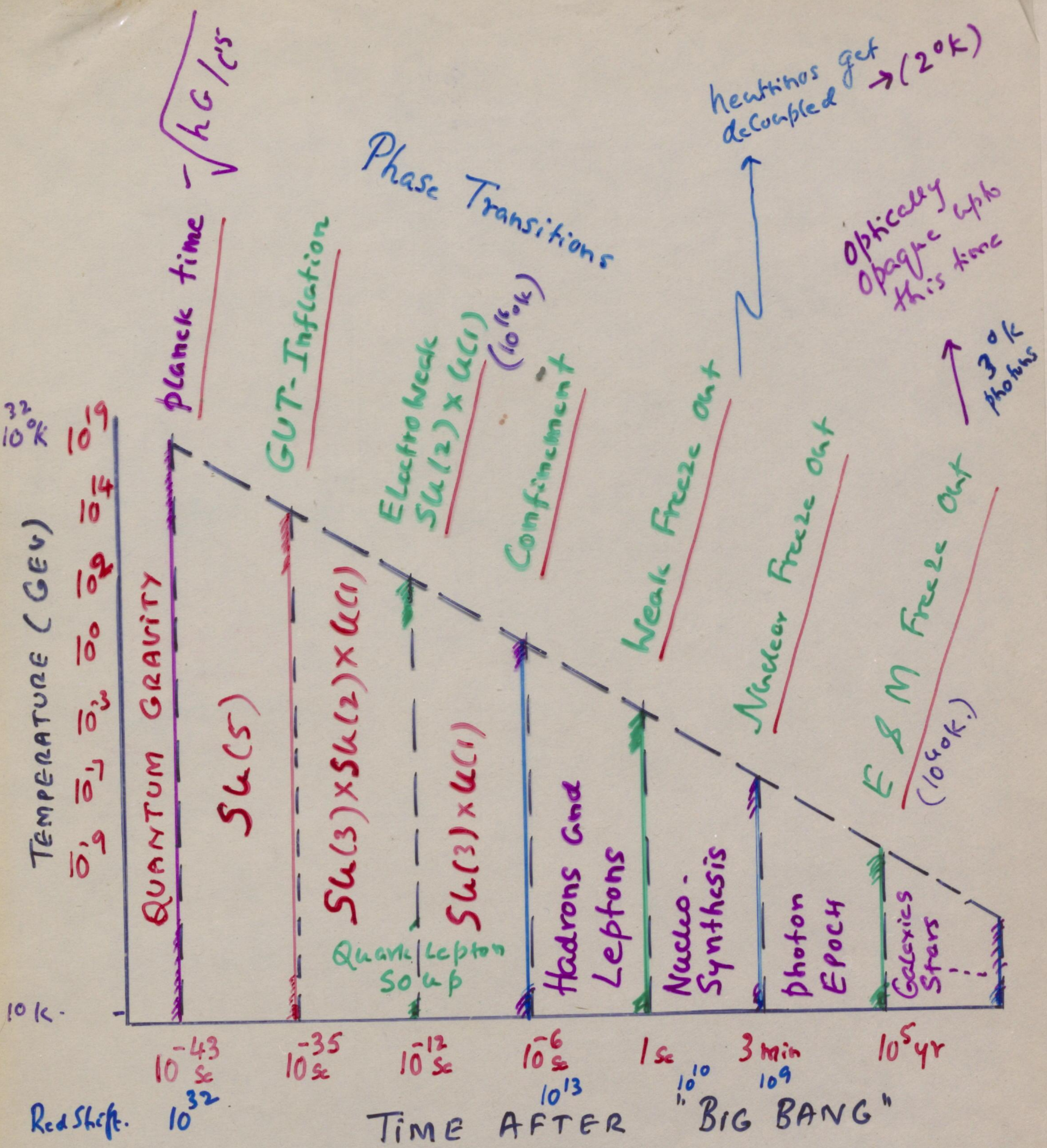
Time	10^{-8} sc	10^{-14} sc	10^{-26}	10^{-32}	10^{-38}	10^{-43} sc.
Temp	10^{15} °K	10^{18} °K	10^{24} °K	10^{27} °K	10^{30}	10^{32} °K.
Size	10^{-16} cms.					10^{-33} cms

Our current knowledge in the field of elementary particle physics (experimental and theoretical) — the behaviour of the forces of nature, relativity and quantum mechanics takes us to as small a time as 10^{-43} s from the Big Bang and not to 0.

May be we will never know what really happened at the Big Bang instant.

We start with { 10^{-43} sc time, size ~ 10^{-33} cms and temperature 10^{32} °K. }

* Ofcourse there are scientists who believe in what is known as 'The Steady State' Universe. There was no beginning. The universe has been there all the time. The fall in density due to expansion is compensated by creation which goes on all the time. What is required is equal to the creation of one atom per year in a large sized hall!



Physics immediately after Creation

Symmetry and Symmetry Breaking

The Universe in the light of Modern Physics and Astronomy

- The Universe is not just the twinkling Stars, the Planets, the Constellations that we see with our naked eyes or with a small telescope. There is much more to it than meets the eye!
- It is more a four dimensional drama with episodes going back to billions of years. Eventhough the sky looks beautiful, majestic and serene, the Universe is characterized by events of extreme violence.
- It is more like what Arjuna saw when the Divya Chaksush was given to him by Krishna, as narrated in the 11th. Chapter of Bhagavad Gita. Only the Characters are inanimate than animate as we shall see.
- The wide range is reflected in the famous line "Anoraneeyan Mahato-Maheeyan"

- As we observe to-day, the universe is expanding and at a temperature of 3°K.

- This leads to the scenario — as we go back in time the universe was smaller and hotter.

- The table shows the relation between the scale factor (compared to the present size of the universe), the time from the Big Bang, and the temperature of the universe and the mean density.

- In order to understand the different physical processes that dominated the universe at different times in its history as the size, density and temperature varied, it is necessary to familiarise ourselves with the interplay between particles and radiation — the knowledge that we have gained in high energy physics through study of cosmic rays and at accelerators.

* At this stage the Universe had two types of particles - Carriers of mass
  Carriers of force (Gravitons)

* At 10^{-35} sec the Strong Force too fell out of the Grand Unified Force

* The single type of mass carrying particle became two - Leptons and quarks

* The Universe was the size of a bowling ball and 10^{60} times denser than the densest atomic nucleus - getting colder and thinner rapidly

* 10^{-10} Seconds - The firmament reached the Weinberg - Salam - Glashow transition Point - the Weak and EM forces broke away.

* Four Interactions are now present - three families of quarks and leptons

The basic Components of the World have been formed.

The Big Bang Scenario

(According to High Energy Particle Physics and GUT)

* Before Big Bang - Something like vacuum.
* At Big Bang - Something happens !
* "That Something was an inconceivably violent Explosion hotter than the hottest Supernova and Smaller than the Smallest quark - Contained the Stuff of everything around us"
* The Universe Consisted of one type or just one particle.
* Detonating outward it may have doubled in size every 10^{-35} Seconds
* Almost no time passed between the birth of the Universe and the birth of Gravity
* By 10^{-43} Second - every bit of matter was Crushed with in a Space Smaller than the atomic Nucleus (10^{-13} cms)
* But the Cosmos was Cool enough to allow the Symmetry to break and let Gravity out.

TOWARDS THE END OF THE UNIVERSE

OPEN UNIVERSE

10^{9} y Sky Stops [illegible]

10^{11} y Stars Stop Radiating
Pitch Black Sky
Gravity dominates → NOW
Formation of Galactic and Super Galactic
Black holes; Stars Cool White Dwarfs,
Neutron Stars, Planets etc.

[illegible] of Super Galactic Black hole ~ [illegible]

3°K Microwave [illegible] & 10^{-18} K

Life Time of Super Galactic
Black Hole ~ [illegible] y

Compression due to Quantum Mechanical
Tunneling
All Stars [illegible] Iron → B.H

In $10^{10^{77}}$ years → Everything Accreted
to Black Holes.

[illegible] [illegible] change if ① Neutrinos have a
finite mass since the "Number of Neutrinos ≃
Number of Photons in the Universe"

② Protons Decay.

TOWARDS THE END OF THE UNIVERSE

CLOSED UNIVERSE [illegible] 16 [illegible]

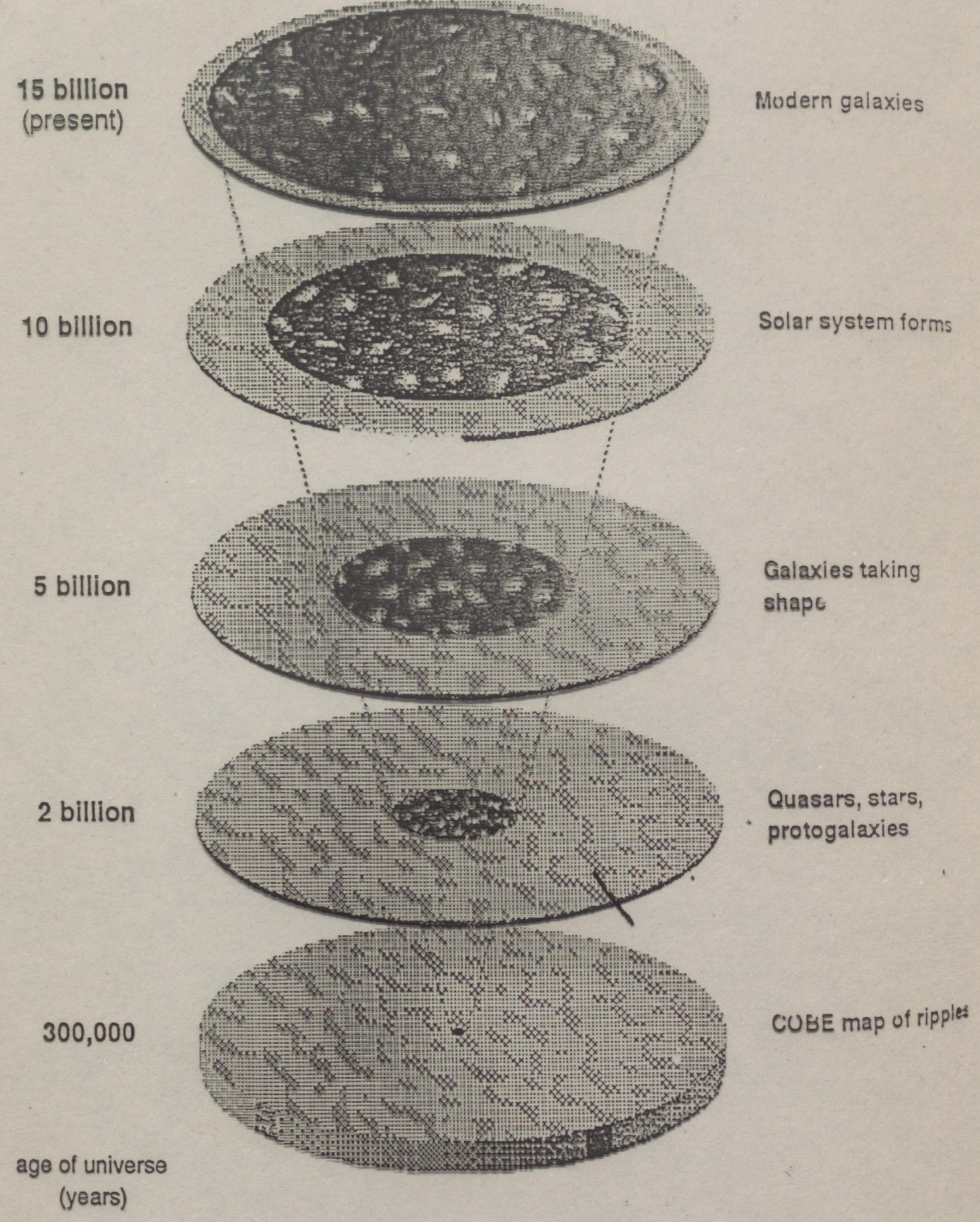
Time	Temp	Radius	Comments
Time Now (Even Zero Bang)	3°K	2×10^{10} ly	
	1·5°K	4×10^{10} ly	
[illegible]	300°K	2×10^{8} ly	
	3000°K	2×10^{7} ly	
	10^{7} °K	6000 ly	
	10^{10} °K	6 ly	
	10^{11} °K	[illegible] ly	Dissolving of Elementary Particles

[illegible] Quantum Mechanical [illegible] size of [illegible]
(described by [illegible] [illegible]
[illegible] [illegible]

Time Table of Creation

Time From Big Bang	Temperature	Typical Energy	Phenomena Scenario
10^{-43} s	10^{32} °K	10^{19} Gev.	Gravity dominates Quantum Gravity?
10^{-37} s	$> 10^{29}$ °K	$> 10^{16}$ Gev	Strong, Weak, EM Forces United. Quark Soup.
10^{-33} s	10^{27} °K	10^{14} Gev	Super heavy bosons (X particles) Matter-Anti Matter asymmetry determined.
10^{-9} s	10^{15} °K	10^{2} Gev	Freezing of W production Weak Interactions get weaker than EM
10^{-2} s	10^{13} °K	1 Gev	quarks combine to make hadrons - Protons neutrons
100 s	10^{9} °K	10^{-4} Gev	Nucleo Synthesis Helium, Deuterium Cre[illegible]
10^{6} years	10^{3} °K	1/10 ev	Background Radiation escapes and fills the [illegible] space, U.V. X-ray etc. cannot go before this time.
10^{10} yrs	3° K	10^{-3} ev	Galaxies, Solar System, Life
Now →			
Future $\leq 10^{32}$ yrs	[illegible]		All [illegible] erodes if no [illegible] collapse takes [illegible] Big Crunch?

Big Bang:
The Expanding and Evolving Universe



- The Universe is filled with Matter and Radiation.

- Matter : Made up of elements Hydrogen - Uranium. (92)
  ↓ Molecules, Atoms
  ↓ Protons, Neutrons, electrons.
  β-decay added the Neutrino to this list.

Mass Range	10^{-24} gms	(Proton)
	10^{56} gms	(Universe)
Size	10^{-13} cms	(Proton)
	10^{30} cms	(Universe)

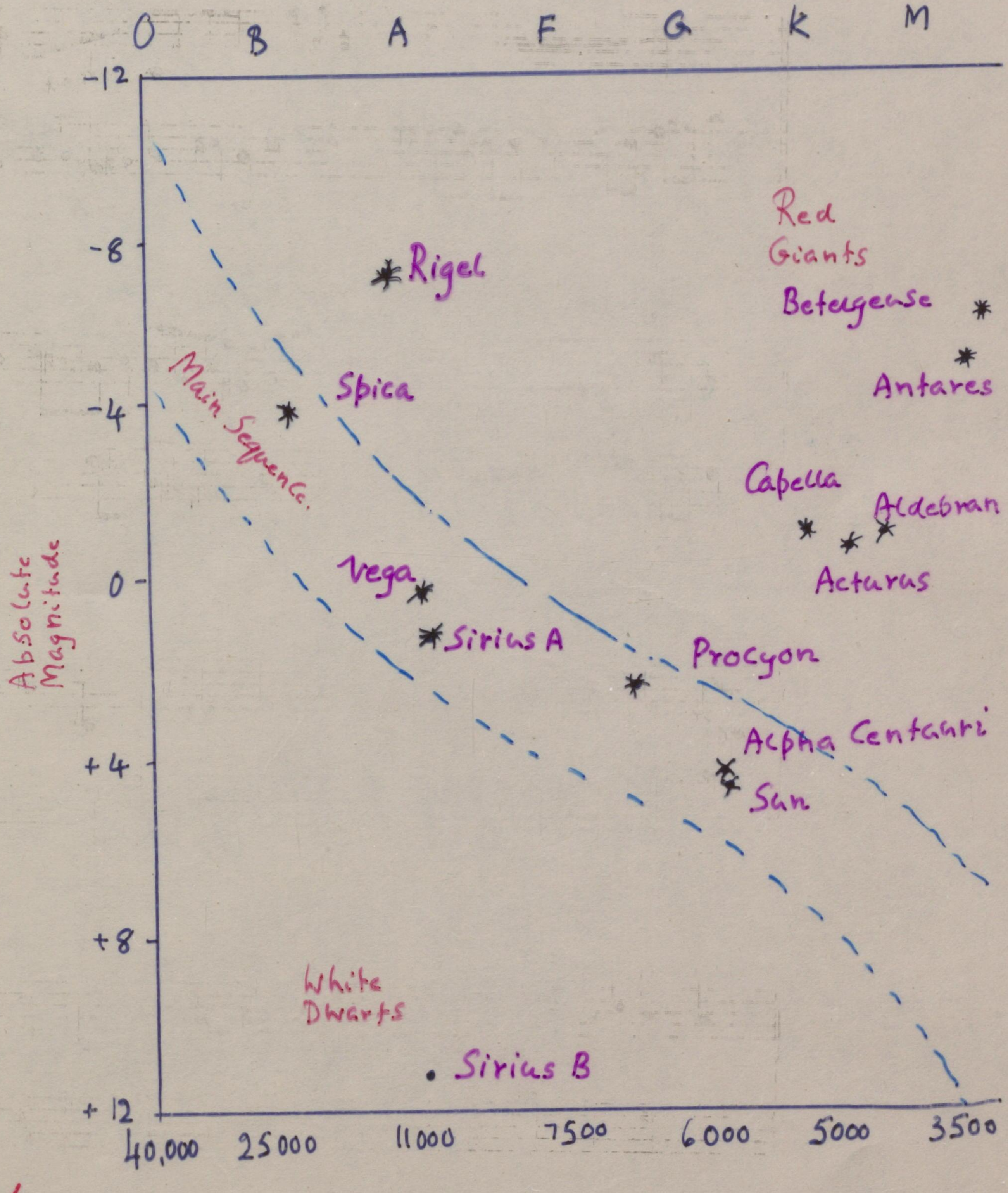
- Radiation : The entire Electromagnetic Spectrum ranging from long wavelength Radio waves to ultra high Energy γ-rays.

  Radio, millimeter, Infrared, optical, ultraviolet, X-ray, γ-ray.

  The most significant for Cosmology is the 3° K - Microwave Radiation.

- Neutrinos Gravitational Waves. Very difficult to detect experimentally.
  Cosmologically very important.

Oh Be A Fine Girl & Kiss Me.



Spectral lines.

SAHA's Theory. –
Temp. pressure - Composition.

Jupiter

- Named after the king of ancient Roman gods.
- 318 times the mass of the earth.
- Volume - can accommodate 1400 earths inside.
- If 5-10 times heavier, would have been a small star
- Atmosphere - Hydrogen, Helium, methane, Ammonia, - thousands of mile deep atmosphere.
- Hurricanes - Red Spot - large enough to swallow the earth - wind velocities of 300 miles/hr.
- 13-14 moons trapped around Jupiter
- The voyager I discovered in 1979, a ring of dark rocks and dust around Jupiter

July 1994 - Shoemaker - Levy 9 Comet chunks hitting Jupiter

78% Hydrogen in the atmosphere of Jupiter. Comet expected to bring oxygen to make water vapour. No evidence yet.

Astronomy

1. Our place in the Universe – between MACRO and MICRO worlds

2. Distance Scales in the Universe.

3. Astronomical Methods – not just optical telescopes alone – Space Telescopes. Underground telescopes.

   [Slides]

4. Astronomical objects – Stars, galaxies, . . .
   [SLIDES] Planets – Jupiter, Saturn, Mars

5. New knowledge – Neutron Stars, Black holes, Quasars.

6. Matter and Radiation in the Universe

7. The Expanding Universe – Early Universe

8. Origin of elements – Cosmic Kitchen

9. Big Bang Explosion

10. Is there life elsewhere or are we alone in this Universe.

HIGH ENERGY PHYSICS AT ACCELERATORS

1950 – 1983   3 GeV – 400 GeV – 10^{12} eV.

(i) Detailed Studies of all particles discovered in Cosmic Rays.

(ii) Beams of protons, pions, μ-mesons, K-mesons, Neutrinos.

(iii) Discovery of Resonances

(iv) Break down of parity.

(v) Discovery of Ω^-

(vi) ν_μ, ν_e, $\bar{\nu}_\mu$, $\bar{\nu}_e$

(vii) Ψ - Charm.

(viii) Scattering experiments with neutrinos → Partons - Quarks.

(ix) τ-meson ν_τ (?)

(x) Neutral Currents

(xi) High P_t, $N\bar{N}$ Cross Section jets

QCD Effects.

(xii) $W^\pm$, Z^0