Re-Creating the Big Bang

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What is the Big Bang ?

Why Re-Create it ?

How to do it ?

Summary

Introduction : What is the Big Bang Theory ?

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- Hubble's Expansion Law. $\Longrightarrow$
  Past : Universe was Denser, although
  Now : It is Rarer.

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- Cosmic Microwave Background Radiation (CMBR) — Strongest Evidence. (1978 & 2006 Nobel Prizes)
  - Most perfect black body radiation spectrum.
  - $T \sim 3000^\circ$ K, redshifted due to expansion $T \sim 2.726^\circ$ K.

Earliest WMAP-snap of Universe: Our Universe at the age of 380,000 years.

Why Re-Create the Early Universe ?

Today t_0
Life on earth
Solar system
Quasars
t = 15 billion years
T = 3 K (1 meV)
Galaxy formation
Epoch of gravitational collapse
Recombination
Relic radiation decouples (CBR)
t = 400,000 years
T = 3000 K (1 eV)
Matter domination
Onset of gravitational instability
t = 3 minutes
Nucleosynthesis
Light elements created - D, He, Li
t = 1 second
T = 1 MeV
Quark-hadron transition
Hadrons form - protons & neutrons
$t = 10^{-6}$ s
T = 1 GeV
Electroweak phase transition
Electromagnetic & weak nuclear forces become differentiated:
SU(3)xSU(2)xU(1) -> SU(3)xU(1)
$t = 10^{-11}$ s
$T = 10^{3}$ GeV
The Particle Desert
Axions, supersymmetry?
Grand unification transition
G -> H -> SU(3)xSU(2)xU(1)
Inflation, baryogenesis,
monopoles, cosmic strings, etc.?
$t = 10^{-35}$ s
$T=10^{15}$ GeV
The Planck epoch
The quantum gravity barrier
$t = 10^{-43}$ s
$T=10^{19}$ GeV

Why Re-Create the Early Universe ?

Quark-hadron transition

Hadrons form - protons & neutrons

♡ To Establish the Physics at the earliest epoch so far, at a few microseconds.

♠ To extend the validity of Big Bang Theory to such epochs, OR expose its limitation.

Strong Interactions

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- Quarks and Leptons – Basic building blocks : Proton (uud), Neutron (udd), Pion $(u\bar{d})$....

- A Variety of Vector Bosons : Carriers of forces.

	Gravity	Weak (Electroweak)	Electromagnetic	Strong
Carried By	Graviton (not yet observed)	W^+ W^- Z^0	Photon	Gluon
Acts on	All	Quarks and Leptons	Quarks and Charged Leptons and W^+ W^-	Quarks and Gluons

Strengths in a ratio $10^{-39} : 10^{-5} : 10^{-2} : 1$

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(Anti-)Quarks come in three (anti-)colours, making gluons also coloured.

Visible Mass of the Universe

- Most visible mass of our Universe is in protons & neutrons, i.e., up & $down$ quarks.

- Discovery of the Higgs particle **may** explain these quark masses. However, a mere simple discovery of the Higgs is **not** sufficient.
  Too small couplings : Can LHC establish them or ILC needed ?

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- The same lattice QCD **predicts** a transition to a new state of matter – Quark Gluon Plasma – as well as its properties. This QGP filled our universe 10-20 μs after the big bang.

Chiral Symmetry & Effective quark mass

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- For (N_f) massless particles, A or B do **not** change into each other: Chiral Symmetry $(SU(N_f) \times SU(N_f))$.

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- Quark-Gluon Plasma is such a phase. It presumably filled our Universe a few microseconds after the Big Bang & can be produced in Relativistic Heavy Ion Collisions.

- Much richer structure in QCD : Quark Confinement, Dynamical Symmetry Breaking.. Lattice QCD should shed light on this all.

Basic Lattice QCD

- Discrete space-time : Lattice spacing a UV Cut-off.
- Quark fields $\psi(x)$, $\bar{\psi}(x)$ on lattice sites.
- Gluon Fields on links : $U_\mu(x)$

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- Discrete space-time : Lattice spacing a UV Cut-off.
- Quark fields $\psi(x)$, $\bar{\psi}(x)$ on lattice sites.
- Gluon Fields on links : $U_\mu(x)$
- Gauge invariance : Actions from Closed Wilson loops, e.g., plaquette.
- Fermion Actions : Staggered, Wilson, Overlap..

Our Workhorse

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Gavai and Gupta, Phys. Rev. D73, 2006.

- The Transition Temperature $T_c \sim 175$ MeV (about 2 Trillion °K).
- Interaction induced mass "melts" at T_c : Chiral Symmetry Restored !
- Quarks behave as if "free" for $T \geq T_c$: Relevant for Heavy Ion Physics.

How to do it ?

How to do it ? By Heavy Ion Collisions

- Where does one find these new phases ? Can they be produced in laboratory ?
- Early Universe — About $10 - 20\mu$s after the Big Bang and in Cores of Dense Neutron Stars.
- Quark-Gluon Plasma can be, and may **indeed** have been, produced in Heavy Ion Collisions in CERN, Geneva and BNL, New York.

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- Necessary Conditions for QGP production :
  - High Energy Density, $\approx$ 1-3 GeV/fm^3 $\sim 1.8 - 5.4 \times 10^{15}$ gm/cc^3.
  - Large System Size, $L \gg \Lambda_{QCD}^{-1} \sim 1$ fm $= 10^{-15}$ meter.
  - Many particles

$\Longrightarrow$ Heavy Ion Collisions at 99.5-99.995 % Velocity of Light.

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Fireball of QGP condenses into hadrons in $\approx 10^{-23}$ seconds.

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  - Quark-Gluon Plasma, any medium in general, interacts with a jet, causing it to lose energy – Jet Quenching.

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  - On-Off test possible – Compare Collisions of Heavy-Heavy nuclei with Light-Heavy or Light-Light.

Azimuthal distributions

Near- side: p+p, d+Au, Au+Au similar

Back- to- back: Au+Au strongly suppressed relative to p+p and d+Au

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- Debye Screening of Quarks $\Longrightarrow$ No binding to Hadrons — Anomalous J/ψ Suppression

Elliptic Flow

♡ For asymmetric collisions of two nuclei, with their centres not aligned :

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◇ Anisotropic Flow & QGP as Perfect Liquid

Summary

- QCD **predicts** new states of strongly interacting matter and is able to shed light on the properties of the Quark-Gluon plasma phase.
- The same theoretical techniques used to prove confinement and to predict the new Quark-Gluon Plasma phase : Testing the standard model in a new domain.
- Our results on correlations of quantum numbers suggest QGP to have quarklike excitations.

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- QCD **predicts** new states of strongly interacting matter and is able to shed light on the properties of the Quark-Gluon plasma phase.
- The same theoretical techniques used to prove confinement and to predict the new Quark-Gluon Plasma phase : Testing the standard model in a new domain.
- Our results on correlations of quantum numbers suggest QGP to have quarklike excitations.
- Heavy Ion Collisions in CERN Geneva, and BNL, New York, have seen tell-tale signs of QGP : Jet Quenching, flow of a 'fluid'...
- Many surprises already and more excitement likely to come at the LHC.