

# New Cyclic Universe Cosmology

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## ABSTRACT

Big Bang theory started its journey with the discovery of CMBR<sup>(1)</sup> by Penzias and Wilson in 1965 as confirmation of prediction of CMBR as the signature or relic of the Big-bang explosion by Gamow and this theory is able to track the history of cosmos to Plank time<sup>(1)</sup>. However it defies the fundamental truths of Physic and Philosophy. Since Big Bang is considered as beginning of Time also. But "How a day can starts without yesterday". So a Cyclic Model<sup>(2)</sup> was proposed long ago by Friedman and Einstein himself in 1930 but ruled out by Tolman's objection<sup>(3)</sup> regarding Entropy. Now the scenario was dramatically changed with the discovery of Accelerated expansion of universe in 1999 by S. Perlmutter<sup>(4)</sup> and String Theory<sup>(5)</sup> which motivates new formulation of Cyclic Universe Cosmology<sup>(6,7,8)</sup>. This model consists of two 4D Branes in one of which we live, separated by very tiny gap along extra 5th dimension. As a result of some kind of spring like interaction arising from Moduli field, branes are getting attracted to each other, collides and bounces repeatedly which corresponds to the evolution of our universe through Big Crunch and Big Bang cyclically with a time period of 14 billion years.

This proposed theory contains no physical singularity since Big Bang is nothing but the temporary collapse of extra 5th dimension according to this new theory. It explain possible existence of Dark energy<sup>(9)</sup> which is assumed to be responsible for accelerated expansion, resolve the problem of entropy and interestingly enough it requires no idea of Inflation<sup>(1)</sup> which was put by hand in Big Bang theory to explain some difficult problem like Fine tuning problem<sup>(9)</sup> etc.

**Keywords:** CMBR, Hubble's Constant H, Big Bang, Big Crunch, Dark Energy, String, D-Brane, Moduli Field, Attractor.

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## INTRODUCTION

To understand cyclic model of the universe, we need the concept of brane (adopted from "membrane") idea of which comes from String Theory (a consistent generalization of quantum field theory in corpora ting Gauge Field Theory and General Theory of Relativity and also a finite quantum theory of Gravity for the first time). In 1990, to make the theory internally consistent, higher dimensional version of string was necessary, called brane. Special interest in cosmology lies in 3-brane .This notion which has now been abstracted from string theory, leads to the idea of Brane-World.(This is not a dreamt picture but emerges from the most sophisticated mathematical model that describes fundamental particles and interactions.) There are two parallel "end of the world brane "or boundary brane (3-brane) in the brane world and there nothing outside it i.e., if one moves from one of the brane along the gap separating them<sup>(5,7)</sup> , he would hit another brane and bounce back from it ,i.e., they are like reflector .These two branes, one visible brane in which we assume to live and other hidden brane , separated by a very tiny gap along extra 5<sup>th</sup> dimension ,are embedded in a 5D space time . The non Gravitational physics is restricted in visible brane while Gravity alone spread along extra 5<sup>th</sup> dimension (which explain why Gravity is so weak.) We cannot see the hidden brane because light can travel only along our visible 3-brane and also we have no way to leave

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our brane even though it is very near to us i.e., separation distance less than the size of the nucleus. Now according to the Cyclic Model<sup>(6,7)</sup> proposed by P.J.Steinherdt and N. Turok, ,these two branes can move towards each other, collide and bounce and after getting separated by finite distant along 5<sup>th</sup> dimension ,then stop (turnaround) and again attracted towards each other .The cycle repeat in every 14 billion years .It is the Bounce after collision that gives rise the effect of Big Bang i.e. , a primordial explosion creating a huge amount of matter and radiation and the Collision corresponds the Big Crunch.

## Dynamics of the Brane<sup>(6)</sup>

Modulus field  $\Phi$  and its potential  $V(\Phi)$  drive the brane movement. According to 4D effective Einstein theory of gravity(reduction from Higher dimensional Theory),

exchange of virtual massive particles between branes gives rises the existence of derived  $\Phi$  and  $V(\Phi)$ . The Physical interpretation of Dark Energy lies in  $\Phi$  and its equation of state i.e.,  $W$  is the ratio of pressure to energy density of  $\Phi$ ,

$$W = \left( \frac{\dot{\varphi}^2}{2} - V(\varphi) \right) / \left( \frac{\dot{\varphi}^2}{2} + V(\varphi) \right) \quad (1)$$

Variation of inter-brane potential  $V(\phi)$  with  $\phi$ . Values of  $\phi$  is related the distance between branes.

- Potential energy domination and cosmic acceleration (duration  $\geq$  trillion years);
  - $\varphi$  kinetic energy becomes non negligible, beginning of decelerated expansion (duration  $\sim 1$  billion years);
  - $H = 0$ , contraction begins;
  - 1 ms before big crunch;
  - $\varphi$  kinetic energy starts to dominate ( $t_{\min} \sim 10^{-30}$  s before big crunch);
  - bounce and reversal from big crunch to big bang;
  - ( $t_{\min} \sim 10^{-30}$  s after big bang);
  - radiation dominated epoch begins  $t_R \sim 10^{-25}$  s after big bang);
  - matter domination epoch begins ( $\sim 10^{10}$  s after big bang).

Dynamical evolution of the Brane System can be explained by exploiting Einstein equation:

$$H^2 = \frac{8\pi G}{3} \left( \frac{\dot{\varphi}^2}{2} + V(\varphi) \right) \quad (2)$$

And

$$\frac{\ddot{a}}{a} = -\frac{8\pi G}{3} \left( \dot{\varphi}^2 - V(\varphi) \right) \quad (3)$$

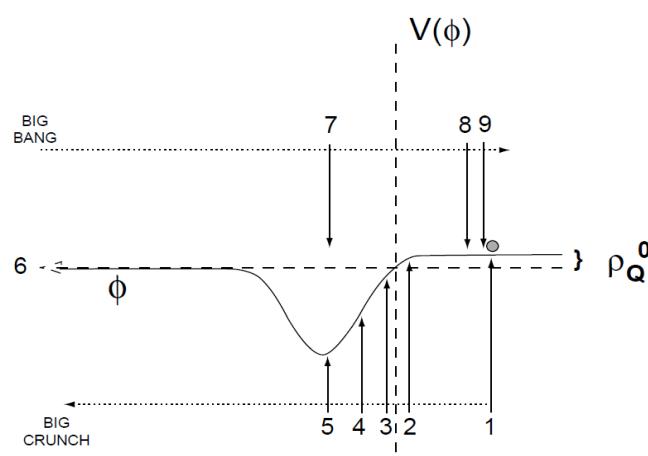


Fig 1

## Stage 1

Present phase of accelerated cosmic expansion is indicated by point:1 where  $V$  is positive with value  $V_0$  (This positive energy density is required to get Cyclic solution) and kinetic energy of the field so equation (3) gives  $\frac{a}{a} > 0$  indicating accelerated expansion and as spends here in the plateau for trillions years ,entropy and density of black holes becomes zero making the universe almost vacuum. Now when  $V$  tends to zero and kinetic energy becomes appreciable and comparable with  $V$ ,  $\left(\frac{a}{a} - V(\phi)\right) \approx 0$  , acceleration stops as  $\frac{a}{a} = 0$  from equation (3)

## Stage 2

As  $\rho$  moves from 1 to 2 potential drops below zero and decrease exponentially and  $\left(\frac{2}{\sigma-1}V(\rho)\right) > 0$  so  $\frac{a}{a'} < 0$ , so phase of decelerated expansion begins which continues for billions of years.

## Stage 3

Here total energy of the system becomes zero when  $V$  takes large negative value making  $H=0$ , expansion stops as is evident from equation (2):

$\left( \frac{\dot{\phi}^2}{2} + V(\phi) \right) \approx 0$  but  $\frac{a}{a'} < 0$ , so contraction starts.

## Stage 4

indicates a phase 1 millisecond before the Big-crunch which is responsible for production of fluctuation on current Hubble-Horizon and stage 5 is the moment  $t_{\min} \sim 10-30$  s before big crunch. At stage: 6, field reverse its direction from minus infinity to finite value. Due to generation of matter and radiation brane potential energy get converted into field kinetic energy and  $\frac{\dot{\phi}}{2}$  compensate negative value of  $V$ , Hubble expansion  $H = \frac{\dot{a}}{a}$  becomes positive causing bounce to occur, so Big crunch get reversed into Big-bang. Stage:7 is the time-reverse situation of the phase between stage 5 and Big-crunch. The field reaches again point 9 to trigger cosmic acceleration again and whole dynamical behavior repeats itself giving birth to a Cyclic Universe.

## Bounce and Escaping from singularity- (Description of observer on Visible Brane(6))

For validity of cyclic model, smooth transition from Big Crunch to Big Bang must have to occur. In 4D effective theory of Gravity, at singularity curvature and energy density diverges to infinite which stop investigation of physics further beyond Big Bang or prior to it. The brane world set up give new insight to the event. This theory reveals that the event when scale factor is zero is an apparent singularity in 4D, actually metric is completely non singular in higher dimensional version of the theory. According to this theory Big Crunch is the momentary collapse of 5th dimension<sup>(5)</sup> and It exhibit no singularity of curvature and energy density at all, when the extra dimension shrink to zero. Two branes collides and bounce from each other and time continue smoothly. The separation of two brane after bounce corresponds to re-expansion in the 4D effective theory of Gravity. Two picture or descriptions can be reconciled. To explore the nature of



singularity in 4D Gravity, One needs to consider the higher dimensional scenario brane world.

For small separation line element in five dimensional world is given by Kaluza –Klein theory,  $ds_5^2 = \exp\left(-\frac{2}{3}\varphi\right)ds_4^2 + \exp\left(2\frac{2}{3}\varphi\right)dy^2$  where  $ds_4$  is the 4D interval,  $y$  is the 5th dimensional spatial coordinate which ranges from 0 to  $L$ . So  $ds_4^2 = a^2(-dt^2 + dx^2)$ , when expressed in conformal time coordinate. So from Friedman equation we have,  $\frac{a'}{a} = \frac{1}{6}\varphi'^2$  with solution,  $a \propto \exp\frac{\varphi}{\sqrt{6}}$  at the Big crunch.

So 3D co-moving volume element  $dt^2a^3\exp\left(\frac{2}{3}\varphi\right) = dt^2\left[\exp\frac{3\varphi}{\sqrt{6}}\right] \times \exp\left(-\frac{2}{3}\varphi\right) = dt^2$  which remains finite even when  $a$  tends to zero and matter density remains finite as well at Big Crunch .Similar arguments applicable for radiation also.

Here Two new variables new variables  $a_0 = 2a \cosh\left[\left(\varphi - \varphi_a\right)/\sqrt{6}\right]$  and  $a_1 = -2a \sinh\left[\left(\varphi - \varphi_a\right)\right]$  are defined which are treated more fundamental than 4D scale factor  $a$  (t).

Line element can be expressed in terms of  $a$  (t) as  $-3da^2 + \frac{1}{2}a^2d\varphi^2$  so for  $a = 0$  is a singularity However, if we use two new variables then it takes the form:  $-\frac{3}{4}(-da_0^2 + da_1^2)$  which does not exhibit any singular behavior even when  $a = \frac{1}{2}\sqrt{a_0^2 - a_1^2}$  vanishes at the light-cone  $a_0 = a_1$  . In similar way Physical quantities like matter and radiation density are expressed as combination of the two: density of matter and radiation

are given by  $\frac{1}{[a\beta(\varphi)]^3}$  and  $\frac{1}{[a\beta(\varphi)]^4}$  respectively where  $\beta(\varphi) = \frac{1}{a}$

is function  $\varphi$  which varies as  $a$  when  $a$  tends to zero. Therefore matter and radiation are finite on the brane at  $a = 0$  .

Figure 2 the trajectory with smooth transition from big-crunch to big-bang Where bounce occurs at  $a=0$  which corresponds to "light-cone" described by  $a_0 = a_1$  in the plot of the  $a_0$ - $a_1$  plane generating a sequence of big crunch and big bang eternally.

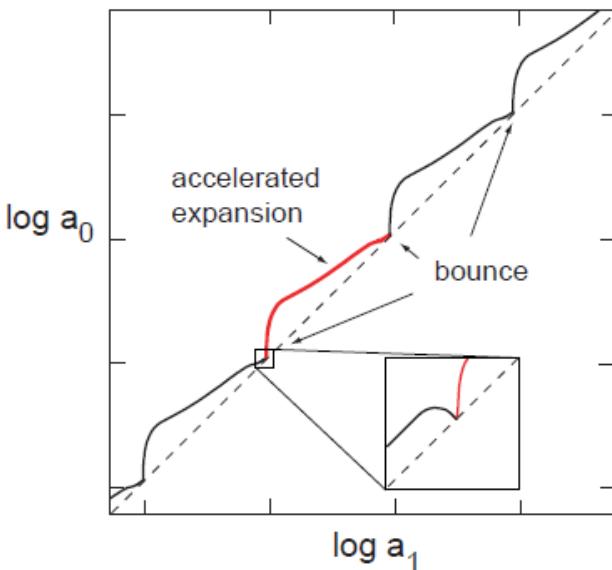


Figure 2

Now the fact that states immediately before and after the bounce are connected can be evident as follows: we consider two equations below:

$\frac{a'}{a} = \frac{1}{6}\varphi'^2$  And  $a^2\varphi' = 0$  where / denotes conformal time derivative.

We can express scalar field in proper time can be expressed as  $\varphi = \sqrt{\frac{2}{3}} \ln\left[\frac{3}{2}H_5(\text{in})t\right]$ .

The integration constant  $H_5$  can be physically interpreted as rate of contraction of the extra dimension. We have before.

$$ds_5^2 = \exp\left(-\sqrt{\frac{2}{3}}\varphi\right)ds_4^2 + \exp\left(2\sqrt{\frac{2}{3}}\varphi\right)dy^2 \quad (7)$$

$$H_5 \equiv \frac{dL_5}{Ldt_5} = \frac{d\left(e^{\sqrt{\frac{2}{3}}\varphi}\right)}{dt_5} = \sqrt{\frac{2}{3}}\varphi e^{\sqrt{\frac{3}{2}}\varphi} \quad (8)$$

$$\text{Where, } L_5 = L \exp\left(\sqrt{\frac{2}{3}}\varphi\right) \text{ and } dt_5 = a \exp\left(-\sqrt{\frac{1}{6}}\varphi\right)d\tau = \exp\left(-\sqrt{\frac{1}{6}}\varphi\right)dt \quad (9)$$

With  $t$  being the FRW proper time .As the extra dimension shrinks to zero ,  $H_5$  tends to constant ,  $H_5(\text{in})$  . Matching condition for the state before and after bounce:  $H_5(\text{out}) = -H_5(\text{in})$  .But the correct matching condition (Israel matching condition), given by

$$H_5(\text{out}) = -(1 + \chi)H_5(\text{in}) > 0. \quad (10)$$

### Cyclic Solution is a Stable Attractor (6)

It may appear that if there is no predictable way collision and bounce, the system trajectory may be chaotic. The fundamental physics will fail to determine to explain the masses and coupling of elementary particles. So the solution must be a stable attractor so that precise trajectory of cosmic evolution must not depend on initial condition and be derived from fundamental laws of physics alone. This theory fulfills all the criteria and physics is predictive and computable.

Nature of the solution can be investigated by studying the phase space trajectory of the system shown in the figure, bellow.

Phase space has following characteristic properties:

- For Flat universe, Friedman equation must be positive. Negative energy state of the system is allowed only for –ve curvature of space. Shaded region is classically forbidden.
- There exists two values at a given point on Phase trajectories on  $(H_5, \varphi)$  plane, one describes expansion (solid line) and other part of the trajectories describes phase of contraction (dashed lines). Two trajectories (neither expanding nor contracting) never intersect each other .But expanding and contracting trajectory may certainly connect with each other.
- Expanding trajectory can turn into a contracting

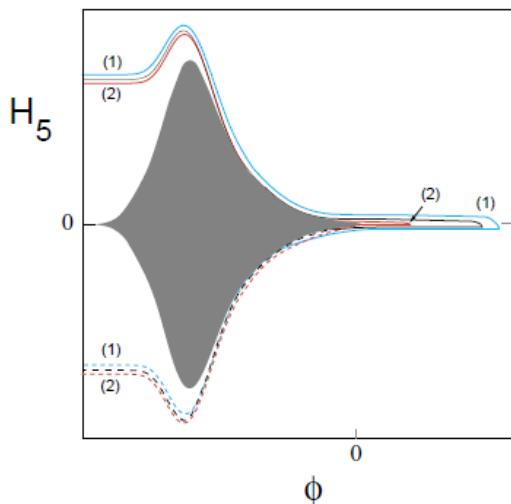


Figure 3

trajectory by two different ways: a) the trajectory must hit the zero density forbidden region (shaded area), for  $H_5$  to pass smoothly through zero,  $\rho$  must vanish and reversal occurs at a finite value of  $\varphi$ .

- b) when the field  $\varphi \rightarrow -\alpha$ .

In the  $(H_5, \varphi)$ -plane the attractor nature of the cyclic solution is exploited (the middle trajectory). Trajectory (1) indicates an overshoot solution which begins with slightly greater velocity ( $H_5$ ) than the attractor, bounces off the forbidden zone of zero energy and then becomes a contracting trajectory whose value of  $H_5$  is smaller than attractor. Trajectory (2) represents an undershoot solution which starts with value slightly less than cyclic value in the expanding phase and get converted into a contracting phase with  $H_5$  having a slightly larger value. In the next bounce, overshoot turns into undershoot and vice-versa. In either case, the deviation decrease from the attractor.

The attractor property of cyclic solution can be evident from the following analysis. Stable attractor solution is represented by the trajectory for which  $H_5$  lies between undershoot and overshoot solution (middle curve) of fig -4. When  $H_5(\text{out})$  is larger(smaller) than the cyclic solution ,it follows trajectory 1(2) and encounter zero density surface

very slightly later than cyclic solution and reverse and end up with a very slightly smaller(larger) value of  $H_5(\text{out})$ .

## CONCLUSION

In conclusion, Inter brane potential  $V(\Phi)$  causes the movement of two "Brane" along an extra 5<sup>th</sup> dimension. When two "Brane" comes closer, collide and then bounce that event gives rise to Big-Bang. The cycle goes through the following stages –Bounces-Expansion-Turnaround- Contraction-Bounce. As the dark energy grows the gap between the "Brane" widens, after attaining maximum gaps they again starts to come closer that corresponds to contraction phase. Thus the epoch of Big-Bang and Big-crunch repeats itself at periodically because attractive inter-brane potential energy keeps attracting the "Brane" together along the extra dimension causing them to collide at every trillion years and due to the presence of Dark energy density make the "Brane" to bounce after collision avoiding ultimate contraction . The concept of Causal-Patch also resolves the Entropy problem. So the 'Phoenix' takes rebirth. So this new model is much more realistic and philosophically satisfactory than BIG-BANG Model.

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