Bouncing Universe and non-BPS Brane

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Based on the work with:

P. von Loewenfeld, N. Moeller, I. Sachs: 0906.3242[hep-th]

Outline

Motivations

The resolution of the big-bang singularity is

- important open fundamental problem in standard cosmology,
  M. Novello and S. Bergliaffa 2008
- natural playground for quantum gravity, e.g. loop quantum gravity and string theory,
  G. Veneziano et al. 1991, 1993, A. Ashtekar 2008, N. Seiberg et al. 2001, S. Kachru et al. 2002
- very often accompanied by the problem of NEC violation, e.g. new ekpyrotic scenario, R. Kallosh, J. Kang, A. Linde, V. Mukhanov 2008

What we have done in our work:
We describe bouncing universe scenarios involving the creation and annihilation of a non BPS D9-branes in type IIA superstring theory.

Model

- **Basic action**

$$S = \frac{1}{2\kappa_{10}^2}\int d^{10}x\,\sqrt{-g}\,e^{-2\Phi}\left(R + 4\,\partial_\mu\Phi\partial^\mu\Phi\right) + S_{\rm T}$$

$$\text{with} \quad S_{\rm T} = \int d^{10}x\,\sqrt{-g}\,e^{-\Phi}L(T,\partial_\mu T\partial^\mu T),$$

where $\kappa_{10}^2 = 8\pi G_{10}$ with G_{10} the ten-dimensional Newton constant.

$$ds^2 = -dt^2 + a(t)^2\,\delta_{ij}dx^i\mathrm{d}x^j + e^{2\sigma(t)}\,\delta_{IJ}dx^I dx^J,$$

we simplify the problem by restricting to the case where $a(t) = e^{\sigma(t)}$.

- Equations of motion

$$
\begin{aligned}
72H^2 - 36H\dot{\Phi} + 4\dot{\Phi}^2 - 2\kappa_{10}^2\, e^{2\Phi}\, \epsilon &= 0, \\
2\ddot{\Phi} - 8\dot{H} + 16H\dot{\Phi} - 2\dot{\Phi}^2 - 36H^2 - \kappa_{10}^2\, e^{2\Phi}\, p &= 0, \\
2\ddot{\Phi} + 18H\dot{\Phi} - 2\dot{\Phi}^2 - 9\dot{H} - 45H^2 - \frac{\kappa_{10}^2}{2}\, e^{2\Phi}\, p &= 0, \\
\dot{\epsilon} + 9H(\epsilon + p) - \dot{\Phi}\, p &= 0.
\end{aligned}
$$

Second and third equations imply

$$
\dot{H} + 9H^2 - 2H\dot{\Phi} - \frac{\kappa_{10}^2}{2}\, e^{2\Phi}\, p = 0\,.
$$

Bounce means

$$
H = 0 \qquad \text{and} \qquad \dot{H} > 0\,.
$$

The pressure p must be *positive*.

- **Tachyon sector**

$$L = V(T)F(X), \quad F(X) = -e^X + 2\sqrt{X}\int_0^{\sqrt{X}} e^{s^2}\, ds, \quad X \equiv -(\partial T)^2$$

N.D. Lambert and I. Sachs 2001,2003

$V(T) = \sqrt{2}\,\tau_9\, e^{-\frac{T^2}{2\alpha'}}$: open string tachyon potential in BSFT.

D. Kutasov et al. 2000, P. Kraus et al. 2000, T. Takayanagi et al. 2000

Some solutions:

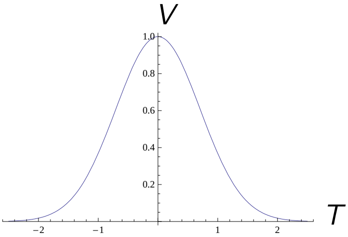
- tachyon kink $T(x) = \chi \sin(x/\sqrt{2\alpha'})$,

  C.G. Callan et al. 1994, A. Recknagel et al. 1998

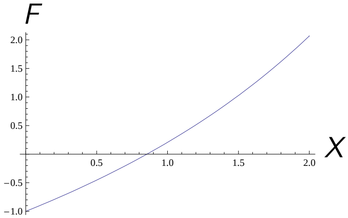
- Sen's rolling tachyon
  $T(t) = A\sinh(t/\sqrt{2\alpha'}) + B\cosh(t/\sqrt{2\alpha'})$.

  A. Sen 2002

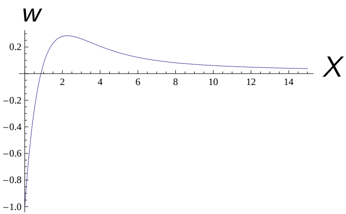
$$\epsilon = \sqrt{2}\tau_9 e^{-\Phi} e^{-T^2 + \dot{T}^2} \quad , \qquad p = \sqrt{2}\tau_9 e^{-\Phi} e^{-T^2} F(\dot{T}^2)\,.$$



(a) tachyon potential



(b) $F = L/V$



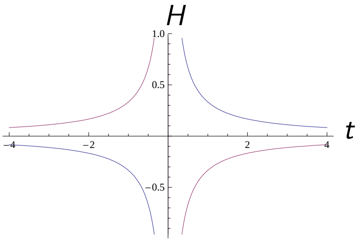
(c) $w = p/\epsilon$

Asymptotic analysis

$|T|$ and $|\dot{T}| \to \infty \Leftrightarrow W \to 0$

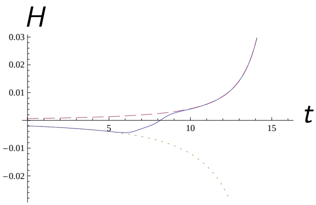
i) $\dot{\Phi} \gg H$: $H \simeq \frac{h}{t^2}$, $\Phi \simeq -\log(|t|)$ as $|t| \to \infty$

ii) $\dot{\Phi} \propto H$: $H \simeq \frac{n}{t-t_0}$, $\dot{\Phi} \simeq \frac{9n-1}{2(t-t_0)}$ with $n = \pm\frac{1}{3}$ as $t \to t_0$

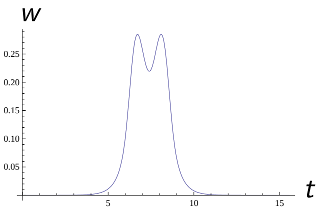


(d) Hubble parameter in pre-big bang and post-big bang solutions

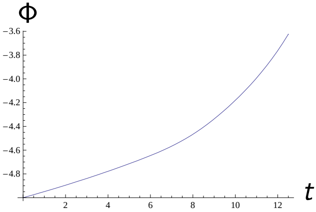
Numerical results



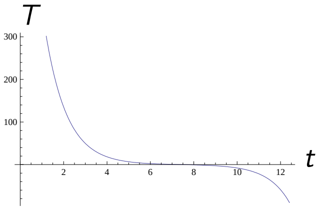
(e) Hubble parameter H



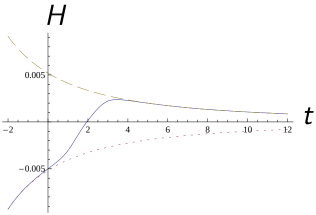
(f) equation of state w



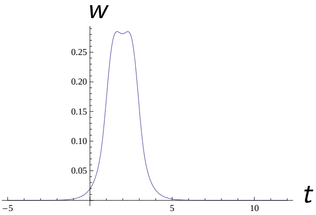
(g) dilaton Φ



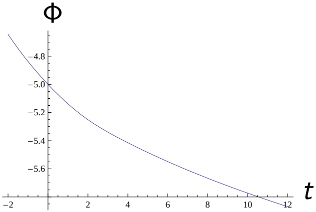
(h) tachyon T



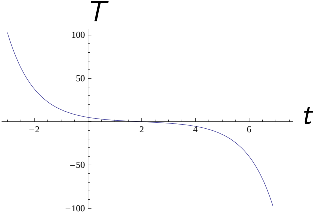
(i) Hubble parameter H



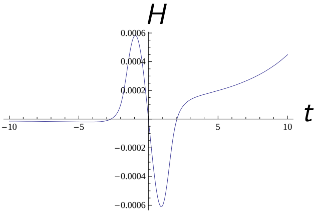
(j) equation of state w



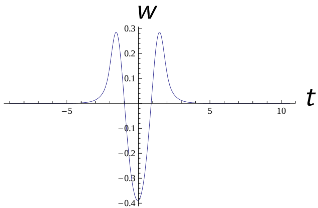
(k) dilaton Φ



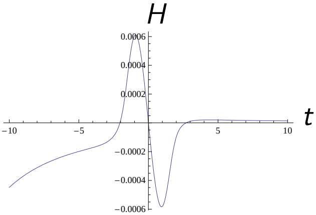
(l) tachyon T



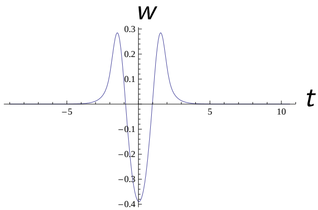
(m) Hubble parameter H



(n) equation of state w



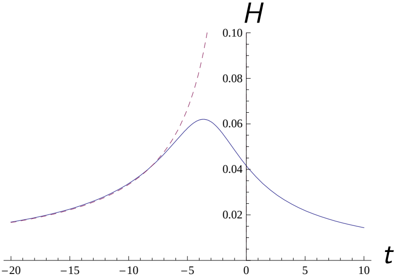
(o) Hubble parameter H



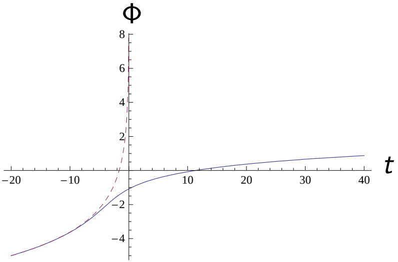
(p) equation of state w

Nonsingular solutions - Phenomenological example

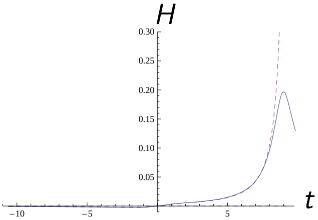
$$-\frac{1}{2\kappa_{10}^2}\int d^{10}x\sqrt{-g}e^{-2\Phi}RV(\Phi) \qquad \text{with} \qquad V(\Phi)\propto e^{\Phi}.$$



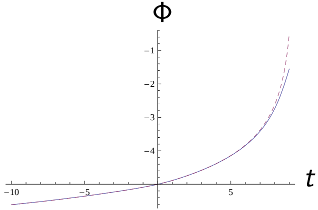
(q) Hubble parameter H



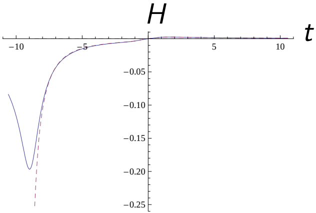
(r) dilaton Φ



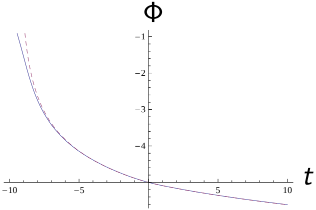
(s) Hubble parameter H



(t) dilaton Φ



(u) Hubble parameter H



(v) dilaton Φ

Conclusion

- In our scenario the bounce takes place as a consequence of the creation and annihilation of a non-BPS brane.
- Our bounce solutions interpolate between contracting and expanding pre-big bang (or post-big bang) solutions.
- The asymptotic singular behavior is the same as that of the pre-big bang scenarios.
- Upon adding a simple dilaton potential the asymptotic curvature singularity can be resolved.

It would be interesting to consider scenarios with a different dynamics for the internal dimensions.