Chaplygin DPG cosmologies

Mariam Bouhmadi-López

CENTRA-IST (Lisbon, Portugal)

Mytilene, 28th September 2007

Work in collaboration with Ruth Lazkoz (EHU, Spain)
Based on 0706.3896 (PLB)

Outline

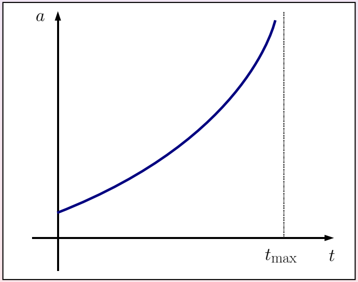
Outline

Introduction

- The expansion of the universe seems accelerating
- Room for $w_0 < -1$?
- In phantom energy model
  - Null energy condition is not satisfied
  - Energy density is a growing function of the scale factor
  - May be big rip singularity
- May be phantom divide crossing

Phantom energy with $w = constant$

- Equation of state $p = w\rho$, $w = \text{const.}$ and $w < -1$
- Energy density $\rho \propto a^{-3(w+1)}$
- Big rip singularity in the future:
  - At a finite cosmic time $t_{\max}$
  - $a \to \infty$, $\rho \to \infty$ and $p \to \infty$

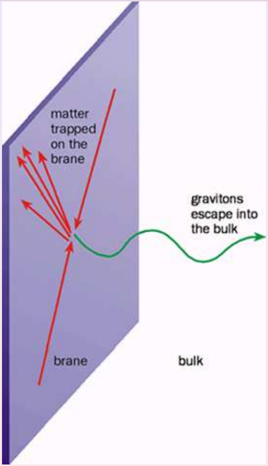


Caldwell, Kamionkowski and Weinberg 2003

Outline

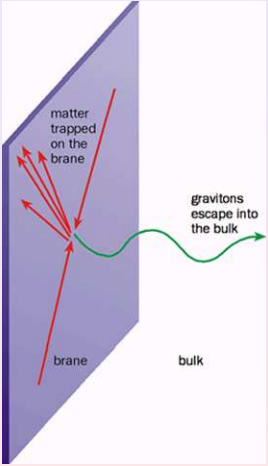
Induced Gravity on the brane

- Brane embedded in a 5D bulk
- Brane action contains 4D scalar curvature
- Two ways of embedding the brane
  - One way generalises RS geometry
  - One way generalises DGP geometry



Dvali,Gabadadze and Porrati Model

- One brane embedded in a 5D Minkowski space-time
- Brane has no tension
- Brane action contains 4D scalar curvature
- Extra dimension is infinite



Dvali, Gabadadze and Porrati ’00
Deffayet ’00

Late-time acceleration on a DGP Brane

- The bulk is flat. Then the expansion of the brane

$$H^2 = \frac{8\pi G}{3}\rho \pm \frac{1}{r_c} H, \qquad r_c = \frac{\kappa_5^2}{2\kappa_4^2}$$

- (+) solution: The self-accelerating solution (Deffayet '00)
- (-) solution: The non self-accelerating solution
  - ΛDGP: Effective phantom-like behaviour. $\rho = \Lambda + \rho_m$
    Sahni, Shtanov '02, Lue, Starkman '04
  - QDGP: Phantom divide crossing is possible. $\rho = \rho_q + \rho_m$.
    The effective 4D phantom description breaks down at some point.
    Chimento, Lazkoz, Maartens, Quiros '06

Outline

CDGP model

- Brane: the non self-accelerating DGP branch
- Matter on the brane
  - Dark energy component is a GCG $\boxed{P = -A/\rho^{\alpha}}$
    $0 < A_s < 1$, $A_s = A/\rho_{\mathrm{ch}_0}^{1+\alpha}$
    Kamenshchik et al ’01, Bilić et al ’01, Bento et al ’02
  - CDM component
- The modified Friedmann equation

$$\boxed{H/H_0 = \sqrt{\Omega_{r_c} + \Omega_m(1+z)^3 + \Omega_{\mathrm{ch}}\left[A_s + (1-A_s)(1+z)^{3(\alpha+1)}\right]^{\frac{1}{1+\alpha}}} - \sqrt{\Omega_{r_c}}}$$

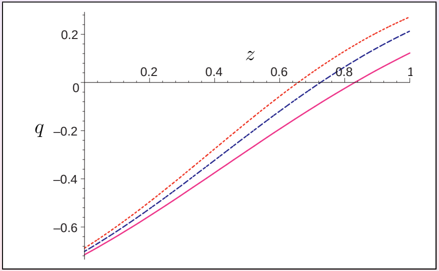
Acceleration on the brane-1-

- There is a mimicry of a closed FLRW universe in the (Ω_m, Ω_{ch}) plane $\boxed{\Omega_m + \Omega_{\rm ch} = 1 + 2\sqrt{\Omega_{r_c}}}$
- The brane never super-accelerates $\dot{H} < 0$
- The brane transits between CDM (past) and de Sitter (future) limits $\Longrightarrow$

  $\exists$ a certain redshift below which the brane accelerates.
- No future singularity

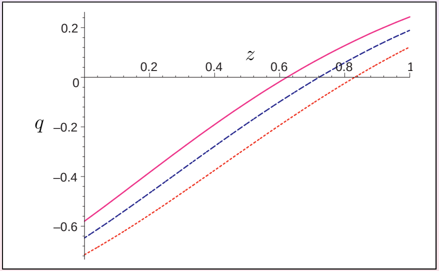
Acceleration on the brane-2-

- For a fixed amount of matter, the late-time acceleration starts sooner the larger is A_s
- $A_s = 0.991, 0.981, 0.971$
- $\Omega_m = 0.2$
- $(\Omega_{r_c}, \alpha) = (0.01, 0.9)$



Acceleration on the brane-3-

- For a fixed A_s, the larger is Ω_m, the latter is the beginning of the cosmic speed up
- $\Omega_m = 0.3, 0.25, 0.21$
- $A_s = 0.991$
- (Ω_{r_c},α)=(0.01,0.9)



Crossing the phantom divide: Effective description-1-

- Effective Friedmann Eq. $\boxed{3H^2 = \rho_m + \rho_{\rm eff}}$
- Effective energy density $\boxed{\rho_{\rm eff} = \rho_{\rm ch} - 3\frac{H}{r_c}}$
- Effective $w_{\rm eff}$ $\boxed{1 + w_{\rm eff} = -\frac{\dot{\rho}_{\rm eff}}{3H\rho_{\rm eff}}}$
- $\rho_{\rm eff}$ is always positive if $\boxed{4A_s(1-A_s) > \left(\frac{4\Omega_{r_c}\Omega_m}{\Omega_{\rm ch}^2}\right)^{1+\alpha}}$
- With this condition the effective picture is always well defined

Crossing the phantom divide: Effective description-2-

- There is a phantom divide crossing if $1 + w_{\rm eff}$ change sign; i.e. $\dot{\rho}_{\rm eff}$ change sign ($\rho_{\rm eff}$ is positive)

$$\boxed{\dot{\rho}_{\rm eff} = \frac{9HH_0^2(1+z)^3}{(H+H_0\sqrt{\Omega_{r_c}})} X}$$

- At high redshift ($z \gg 1$) $\dot{\rho}_{\rm eff}$ is negative $\Longrightarrow 1 + w_{\rm eff} > 0$
- At $z \approx -1$ the quantity $\dot{\rho}_{\rm eff}$ is positive $\Longrightarrow 1 + w_{\rm eff} < 0$

$$\boxed{X \sim \Omega_m H_0 \sqrt{\Omega_{r_c}} \quad \text{for} \quad \alpha > 0}$$

- Therefore, there is a phantom divide crossing if $\alpha > 0$ and $\Omega_m \neq 0$

Crossing the phantom divide: Effective description-3-

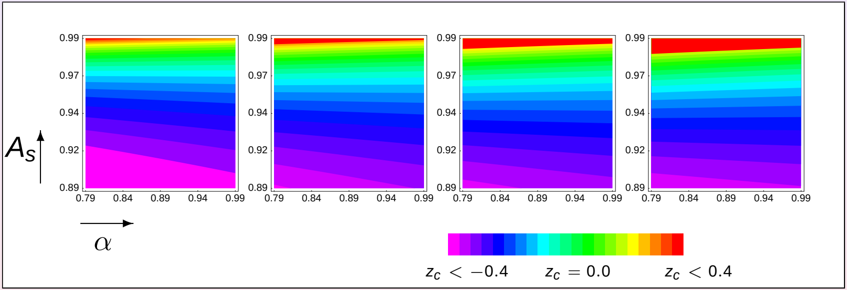
- Why $\Omega_m \neq 0$ is a necessary condition for "crossing the phantom divide"?
  - In absence of CDM the Raychaudhuri equation reads

$$\boxed{2\dot{H} = -(1+w_{\rm eff})\rho_{\rm eff}}$$

  - There is no super-acceleration on the brane (in all cases)
  - Then the phantom divide crossing cannot occur if $\Omega_m = 0$

Crossing the phantom divide: Effective description-4-

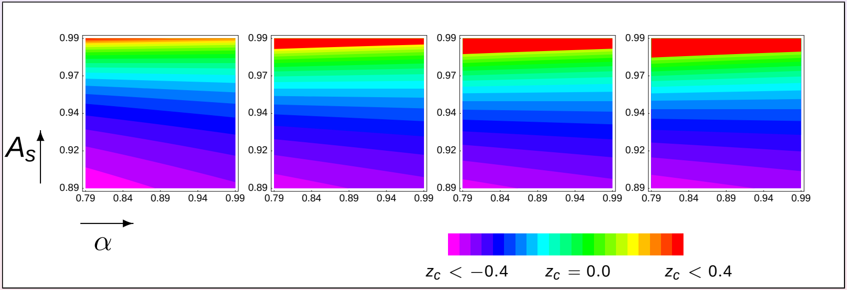
Redshift values z_c at which the crossing takes place



- For a fixed value of Ω_{r_c}, z_c grows with increasing Ω_m
- $\Omega_{r_c} = 0.04$ and $\Omega_m = 0.20, 0.25, 0.30, 0.35$ (left to right)

Crossing the phantom divide: Effective description-5-

Redshift values z_c at which the crossing takes place



- For a fixed value of Ω_m, z_c grows with increasing Ω_{r_c}
- $\Omega_m = 0.25$ and $\Omega_{r_c} = 0.01, 0.04, 0.07, 0.10$ (left to right)

Outline

Summary and Conclusions

- CDGP model: The non self-accelerating (normal) branch of the DGP model filled with dark energy modelled through a Chaplygin gas + CDM
  - can describe the late-time acceleration
  - mimics “crossing the phantom divide”
  - effective description remains valid at all redshift
  - no future singularity