Title: A New Perspective on DGP Gravity

Date: Sep 11, 2007 05:00 PM

URL: http://pirsa.org/07090038

Abstract:

DGP Gravity: Dvali, Gabadadze & Porrati (hep-th/0005016)

- 4-D gravity on a brane in 5-D Minkowski space:

$$= 2M_5^3 \int_{bulk} d^5x\sqrt{-G}\,R(G) + \int_{brane} d^4x\,\sqrt{-g}\,\left(M_4^2\,\mathcal{R}(g) + \mathcal{L}_{\rm matter}\right)$$

- extra dimension is not warped or even compactified

DGP Gravity: Dvali, Gabadadze & Porrati (hep-th/0005016)

- 4-D gravity on a brane in 5-D Minkowski space:

$$= 2M_5^3 \int_{bulk} d^5x\sqrt{-G}\,R(G) + \int_{brane} d^4x\,\sqrt{-g}\,\left(M_4^2\,\mathcal{R}(g) + \mathcal{L}_{\rm matter}\right)$$

- extra dimension is not warped or even compactified
- additional Einstein term appears in brane action
  (and vanishing tension)

DGP Gravity: Dvali, Gabadadze & Porrati (hep-th/0005016)

- 4-D gravity on a brane in 5-D Minkowski space:

$$= 2M_5^3 \int_{bulk} d^5x\sqrt{-G}\,R(G) + \int_{brane} d^4x\,\sqrt{-g}\,\left(M_4^2\,\mathcal{R}(g) + \mathcal{L}_{\rm matter}\right)$$

- extra dimension is not warped or even compactified
- additional Einstein term appears in brane action
  (and vanishing tension)
- behaviour of gravity on brane modified at large distances

→ { at short distances, see 4-D gravity
  { at long distances, see 5-D gravity

DGP Gravity: Dvali, Gabadadze & Porrati (hep-th/0005016)

- 4-D gravity on a brane in 5-D Minkowski space:

$$= 2M_5^3 \int_{bulk} d^5x\sqrt{-G}\,R(G) + \int_{brane} d^4x\,\sqrt{-g}\,\left(M_4^2\,\mathcal{R}(g) + \mathcal{L}_{\rm matter}\right)$$

- extra dimension is not warped or even compactified
- additional Einstein term appears in brane action
  (and vanishing tension)
- behaviour of gravity on brane modified at large distances

→ { at short distances, see 4-D gravity
  { at long distances, see 5-D gravity

- may explain cosmic acceleration **(without Λ!)**

→ brane is self-accelerated

DGP Gravity: Dvali, Gabadadze & Porrati (hep-th/0005016)

- 4-D gravity on a brane in 5-D Minkowski space:

$$= 2M_5^3 \int_{bulk} d^5x\sqrt{-G}\,R(G) + \int_{brane} d^4x\,\sqrt{-g}\,\left(M_4^2\,\mathcal{R}(g) + \mathcal{L}_{\rm matter}\right)$$

- behaviour of gravity on brane modified at large distances
- may explain cosmic acceleration **(without Λ!)**

DGP Gravity: Dvali, Gabadadze & Porrati (hep-th/0005016)

- 4-D gravity on a brane in 5-D Minkowski space:

$$= 2M_5^3 \int_{bulk} d^5x\sqrt{-G}\,R(G) + \int_{brane} d^4x\,\sqrt{-g}\,\left(M_4^2\,\mathcal{R}(g) + \mathcal{L}_{\rm matter}\right)$$

- behaviour of gravity on brane modified at large distances
- may explain cosmic acceleration **(without Λ!)**
- an up-and-down history:

DGP Gravity: Dvali, Gabadadze & Porrati (hep-th/0005016)

- 4-D gravity on a brane in 5-D Minkowski space:

$$= 2M_5^3 \int_{bulk} d^5x\sqrt{-G}\,R(G) + \int_{brane} d^4x\,\sqrt{-g}\,\left(M_4^2\,\mathcal{R}(g) + \mathcal{L}_{\rm matter}\right)$$

- behaviour of gravity on brane modified at large distances
- may explain cosmic acceleration **(without Λ!)**
- an up-and-down history:
  - DGP can be realized with string theory constructions

(Kiritsis et atl `01; Antoniadis et al `02)

DGP Gravity: Dvali, Gabadadze & Porrati (hep-th/0005016)

- 4-D gravity on a brane in 5-D Minkowski space:

$$= 2M_5^3 \int_{bulk} d^5x\sqrt{-G}\,R(G) + \int_{brane} d^4x\,\sqrt{-g}\,\left(M_4^2\,\mathcal{R}(g) + \mathcal{L}_{\rm matter}\right)$$

- behaviour of gravity on brane modified at large distances
- may explain cosmic acceleration **(without Λ!)**
- an up-and-down history:
  - DGP can be realized with string theory constructions (Kiritsis et atl `01; Antoniadis et al `02)
  - DGP has no UV completion (Dubovsky et al; Adams et al `06)

DGP Gravity: Dvali, Gabadadze & Porrati (hep-th/0005016)

- 4-D gravity on a brane in 5-D Minkowski space:

$$= 2M_5^3 \int_{bulk} d^5x\sqrt{-G}\,R(G) + \int_{brane} d^4x\,\sqrt{-g}\,\left(M_4^2\,\mathcal{R}(g) + \mathcal{L}_{\rm matter}\right)$$

- behaviour of gravity on brane modified at large distances
- may explain cosmic acceleration **(without Λ!)**
- an up-and-down history:
  - DGP can be realized with string theory constructions

(Kiritsis et atl `01; Antoniadis et al `02)

  - DGP has no UV completion (Dubovsky et al; Adams et al `06)
  - DGP is unstable – spectrum has ghosts and tachyons!

(Koyama et al; Charmouis et al; Shtanov et al `06)

DGP Gravity: Dvali, Gabadadze & Porrati (hep-th/0005016)

- 4-D gravity on a brane in 5-D Minkowski space:

$$= 2M_5^3 \int_{bulk} d^5x\sqrt{-G}\,R(G) + \int_{brane} d^4x\,\sqrt{-g}\,\left(M_4^2\,\mathcal{R}(g) + \mathcal{L}_{\rm matter}\right)$$

- behaviour of gravity on brane modified at large distances
- may explain cosmic acceleration **(without Λ!)**
- an up-and-down history:
  - DGP can be realized with string theory constructions (Kiritsis et atl `01; Antoniadis et al `02)
  - DGP has no UV completion (Dubovsky et al; Adams et al `06)
  - DGP is unstable – spectrum has ghosts and tachyons! (Koyama et al; Charmouis et al; Shtanov et al `06)
  - DGP is stable/ghosts irrelevant (Koyama; Deffayet et al; Dvali `06)

DGP Gravity: Dvali, Gabadadze & Porrati (hep-th/0005016)

- 4-D gravity on a brane in 5-D Minkowski space:

$$= 2M_5^3 \int_{bulk} d^5x\sqrt{-G}\,R(G) + \int_{brane} d^4x\,\sqrt{-g}\,\left(M_4^2\,\mathcal{R}(g) + \mathcal{L}_{\rm matter}\right)$$

- behaviour of gravity on brane modified at large distances
- may explain cosmic acceleration **(without Λ!)**
- an up-and-down history:

As it stands, DGP gravity is a **BAD** model !!

New perspective: take a 5-D point of view!

DGP model is 5-D Einstein gravity
coupled to certain class of matter/branes

Solutions of DGP Gravity:

Equations of motion:

Bulk: $$R_{ab} - \tfrac{1}{2} R\, G_{ab} = 0$$

Brane: $$2M_5^3\, K_{\mu\nu} = -M_4^2 \left(\mathcal{R}_{\mu\nu} - \tfrac{1}{6}\mathcal{R}\, g_{\mu\nu}\right)$$

Israel junction conditions

- brane stress tensor modified by geometric terms
- assumed Z_2 symmetry about the brane

$$\longrightarrow \Gamma_{\mu\nu} = K^{+}_{\mu\nu} + K^{-}_{\mu\nu} = 2K_{\mu\nu}$$

- assumed no additional matter on brane

Solutions of DGP Gravity:

Equations of motion:

Bulk: $$R_{ab} - \frac{1}{2} R\, G_{ab} = 0$$

Brane: $$2M_5^3\, K_{\mu\nu} = -M_4^2 \left(\mathcal{R}_{\mu\nu} - \frac{1}{6}\mathcal{R}\, g_{\mu\nu}\right)$$

"cut-and-paste" to build symmetric solutions: (Deffayet '01)

- choose a known solution of 5-D Einstein equations, eg,

  Minkowski: $ds^2 = -dt^2 + dr^2 + r^2 d\Omega_3^2$ X 2

- choose a simple symmetric brane geometry, eg,

  FRW: $ds^2 = -d\tau^2 + a(\tau)^2\, d\Omega_3^2$

- choose simple embedding ansatz, eg, $r = a(\tau)$

  and cut-and-paste with Israel conditions solving trajectory

(Deffayet '01)

solution: $$a(\tau) = \frac{1}{H_0}\cosh(H_0\tau)$$

with $$H_0 = 2M_5^3/M_4^2$$

Brane geometry corresponds to 4-D deSitter space!

Self-Accelerating brane!

(Deffayet '01)

solution: $$a(\tau) = \frac{1}{H_0}\cosh(H_0\tau)$$

with $$H_0 = 2M_5^3/M_4^2$$

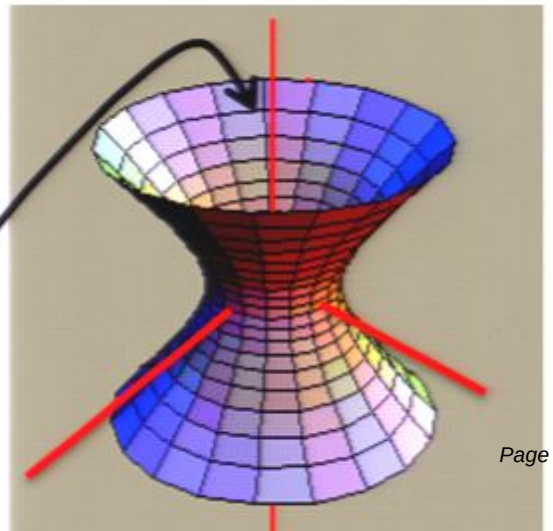
Brane geometry corresponds to 4-D deSitter space!

Self-Accelerating brane!

hyperboloid in 5-D Minkowski:

$$r^2 - t^2 = H_0^{-2}$$

remove center of space



(Deffayet '01)

solution: $$a(\tau) = \frac{1}{H_0}\cosh(H_0\tau)$$

with $$H_0 = 2M_5^3/M_4^2$$

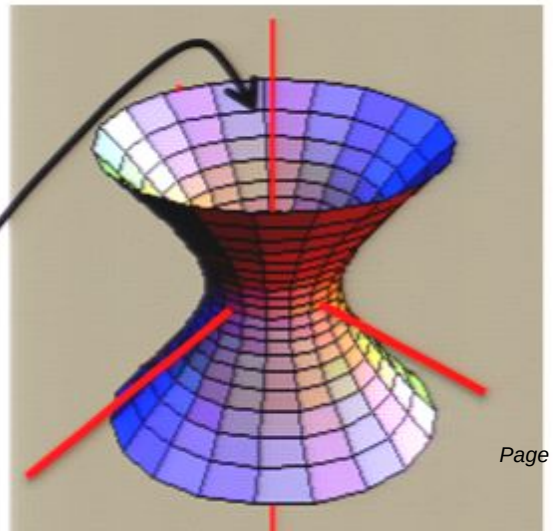
Brane geometry corresponds to 4-D deSitter space!

Self-Accelerating brane!

hyperboloid in 5-D Minkowski:

$$r^2 - t^2 = H_0^{-2}$$

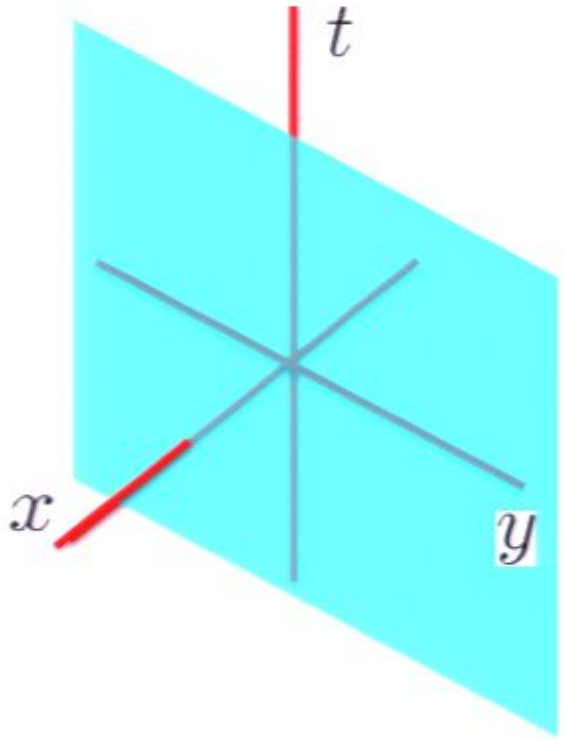
remove center of space



(also find: Normal branch)

Normal branch: $r \to \infty$ (that is $x = const.$)

flat 4-D brane



(Deffayet '01)

solution: $$a(\tau) = \frac{1}{H_0}\cosh(H_0\tau)$$

with $$H_0 = 2M_5^3/M_4^2$$

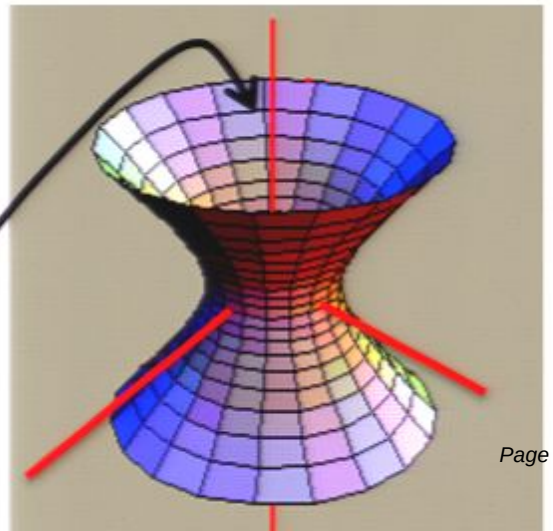
Brane geometry corresponds to 4-D deSitter space!

Self-Accelerating brane!

hyperboloid in 5-D Minkowski:

$$r^2 - t^2 = H_0^{-2}$$

remove center of space



(also find: Normal branch)

DGP phenomenology versus fine-tuning:

$$H_0 = \frac{2M_5^3}{M_4^2} \sim \text{Hubble scale} \sim 1/(10^{26}\ metres)$$

$$M_4 \sim \text{Planck scale} \sim 1/(10^{-35}\ metres)$$

$\longrightarrow$ $M_5/M_4 \sim 10^{-20}$ pheno. requires severe fine-tuning!

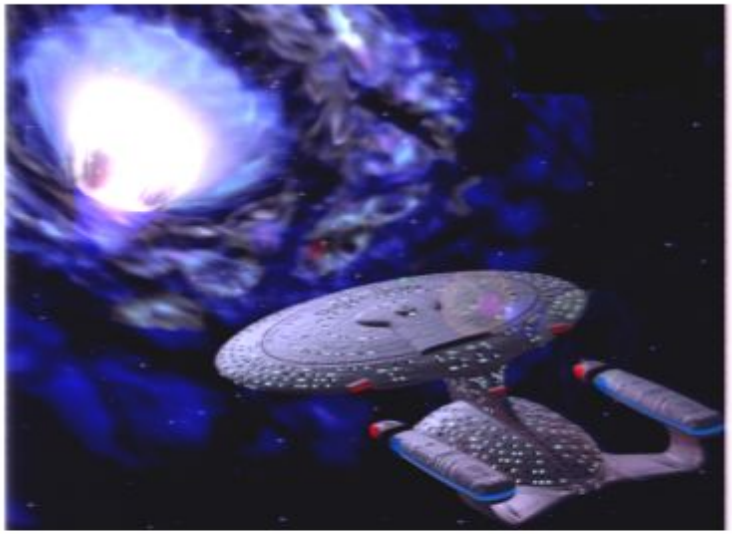
DGP phenomenology versus fine-tuning:

$$H_0 = \frac{2M_5^3}{M_4^2} \sim \text{Hubble scale} \sim 1/(10^{26}\ metres)$$

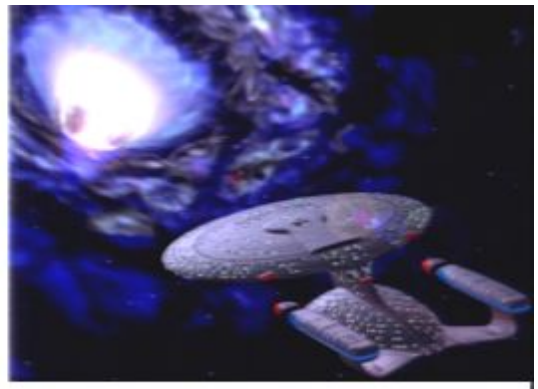
$$M_4 \sim \text{Planck scale} \sim 1/(10^{-35}\ metres)$$

$\longrightarrow$ $M_5/M_4 \sim 10^{-20}$ pheno. requires severe fine-tuning!

SA brane as a wormhole:



SA brane as a wormhole:



- wormholes need negative energy density?

SA brane as a wormhole:

- wormholes need negative energy density?

effective stress-tensor for DGP brane:

$$4M_5^3\left(K_{\mu\nu}-K\,g_{\mu\nu}\right)=T_{\mu\nu}^{brane}=-2M_4^2\left(\mathcal{R}_{\mu\nu}-\tfrac{1}{2}\mathcal{R}\,g_{\mu\nu}\right)$$

SA brane as a wormhole:

- wormholes need negative energy density?

effective stress-tensor for DGP brane:

$$4M_5^3\left(K_{\mu\nu}-K\,g_{\mu\nu}\right)=T_{\mu\nu}^{brane}=-2M_4^2\left(\mathcal{R}_{\mu\nu}-\tfrac{1}{2}\mathcal{R}\,g_{\mu\nu}\right)$$

Sign !!

$$\sigma_{\rm eff}\equiv -6\,M_4^2H^2$$

SA brane as a wormhole:

- wormholes need negative energy density?

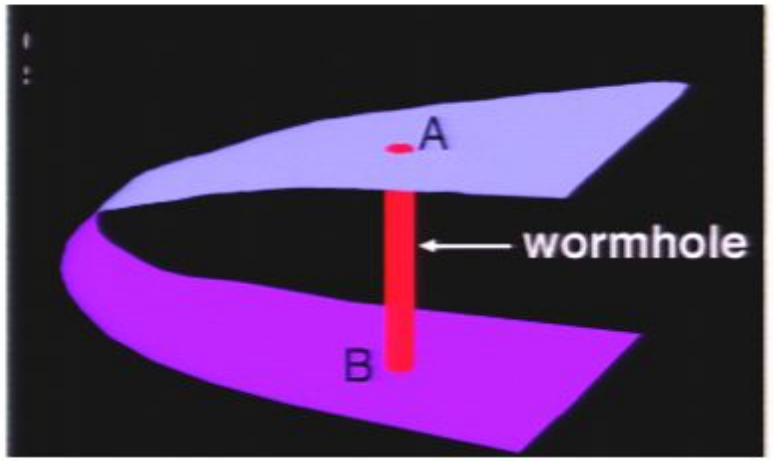
  effective stress-tensor for DGP brane:

$$\sigma_{\rm geo} \equiv -6\, M_4^2 H^2$$

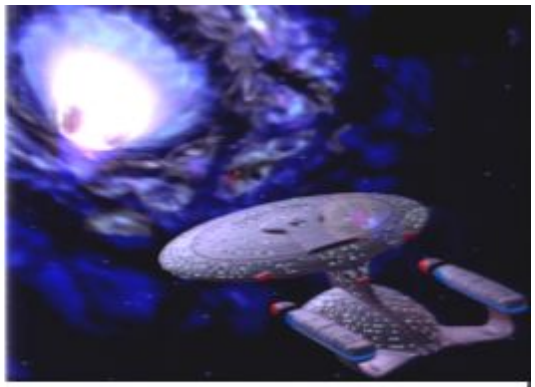
- wormholes can generate closed time-like curves?

  yes, even though wormhole mouth rapidly expands here

  → colliding branes



SA brane as a wormhole:



- wormholes need negative energy density?

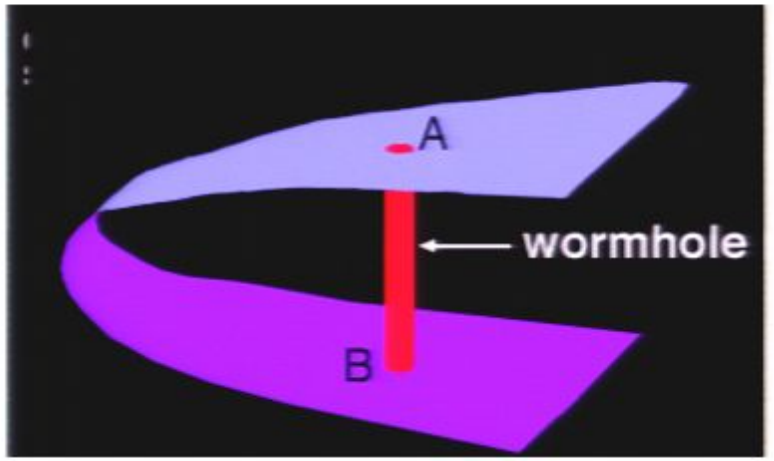
  effective stress-tensor for DGP brane:

$$\sigma_{\rm geo} \equiv -6\, M_4^2 H^2$$

- wormholes can generate closed time-like curves?

  yes, even though wormhole mouth rapidly expands here

  → colliding branes



- wormhole issues ameliorated if brane is Z_2-orbifold

(negative energies? colliding branes? . . .)

New solutions (and new problems):

5-D Schwarzschild

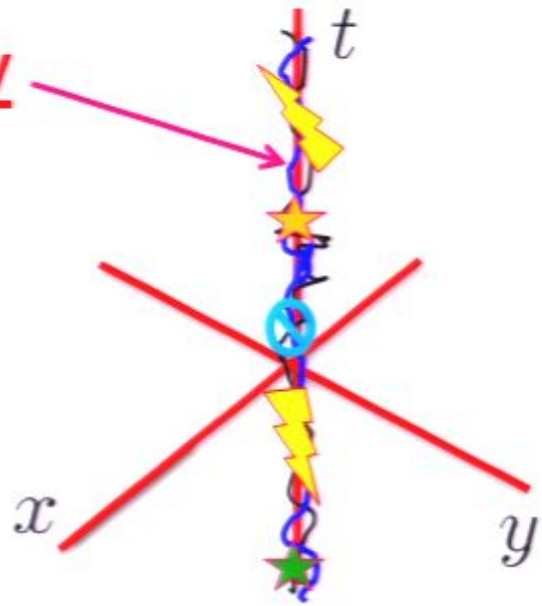
$$ds^2 = -\left(1 + \frac{\mu}{r^2}\right) dt^2 + \frac{dr^2}{1 + \frac{\mu}{r^2}} + r^2 d\Omega_3^2$$

New solutions (and new problems):

5-D Schwarzschild (with negative mass):

$$ds^2 = -\left(1 + \frac{\mu}{r^2}\right) dt^2 + \frac{dr^2}{1 + \frac{\mu}{r^2}} + r^2 d\Omega_3^2$$

Mass: $M = -12\pi^2 M_5^3 \mu$



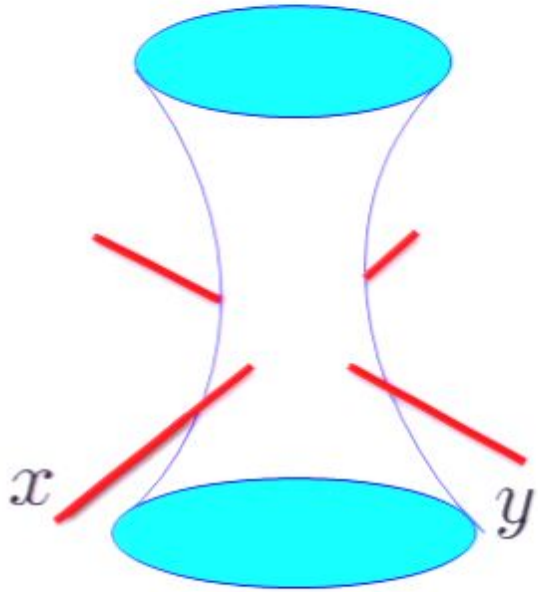
New solutions (and new problems):

5-D Schwarzschild (with negative mass):

$$ds^2 = -\left(1 + \frac{\mu}{r^2}\right) dt^2 + \frac{dr^2}{1 + \frac{\mu}{r^2}} + r^2 d\Omega_3^2$$

Mass: $M = -12\pi^2 M_5^3 \mu$

But cut-and-paste will remove center of space with SA brane!



New solutions:

5-D Schwarzschild (with negative mass):

$$ds^2 = -\left(1 + \frac{\mu}{r^2}\right) dt^2 + \frac{dr^2}{1 + \frac{\mu}{r^2}} + r^2 d\Omega_3^2$$

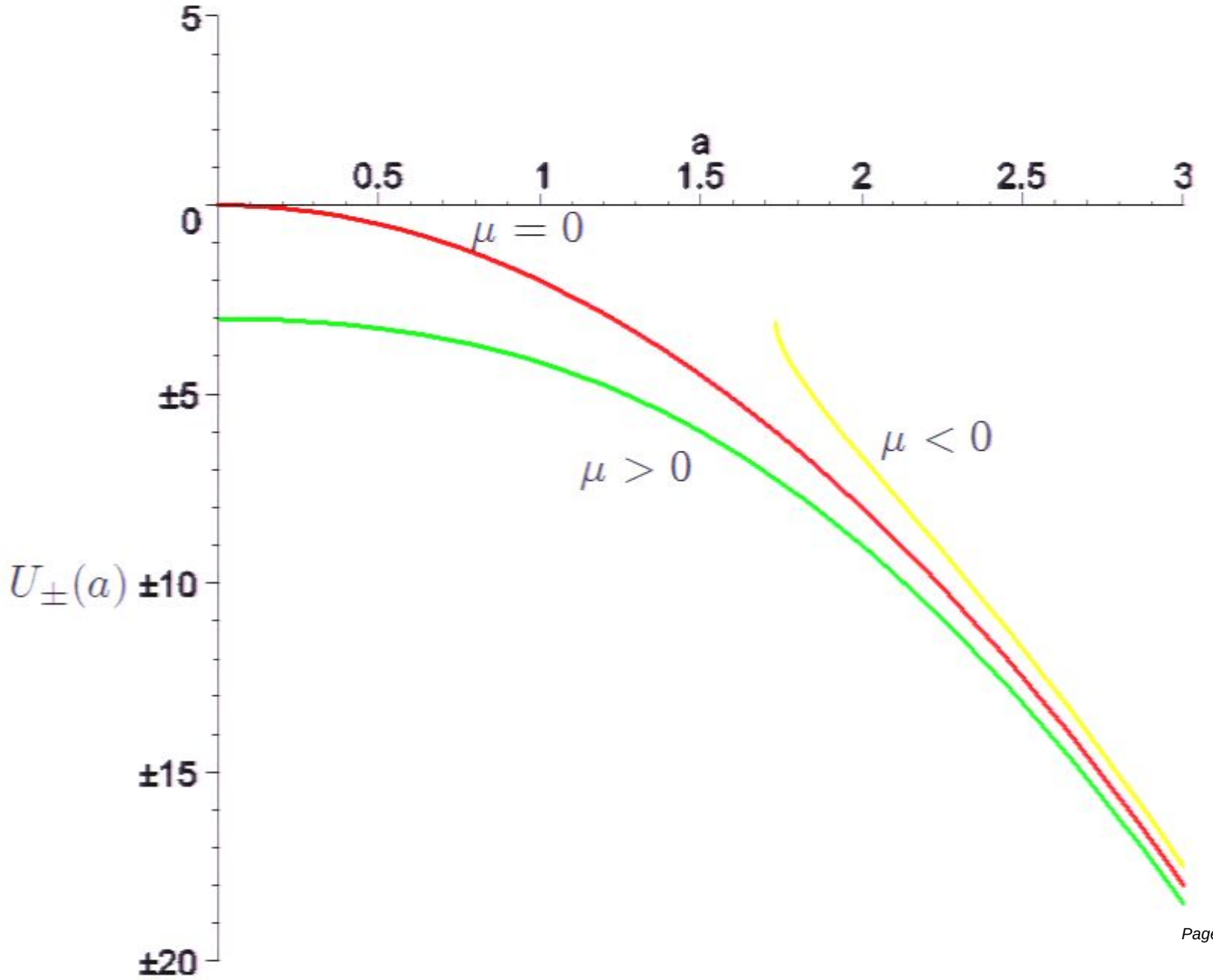
FRW brane: $ds^2 = -d\tau^2 + a(\tau)^2 \, d\Omega_3^2$

embedding: $r = a(\tau)$

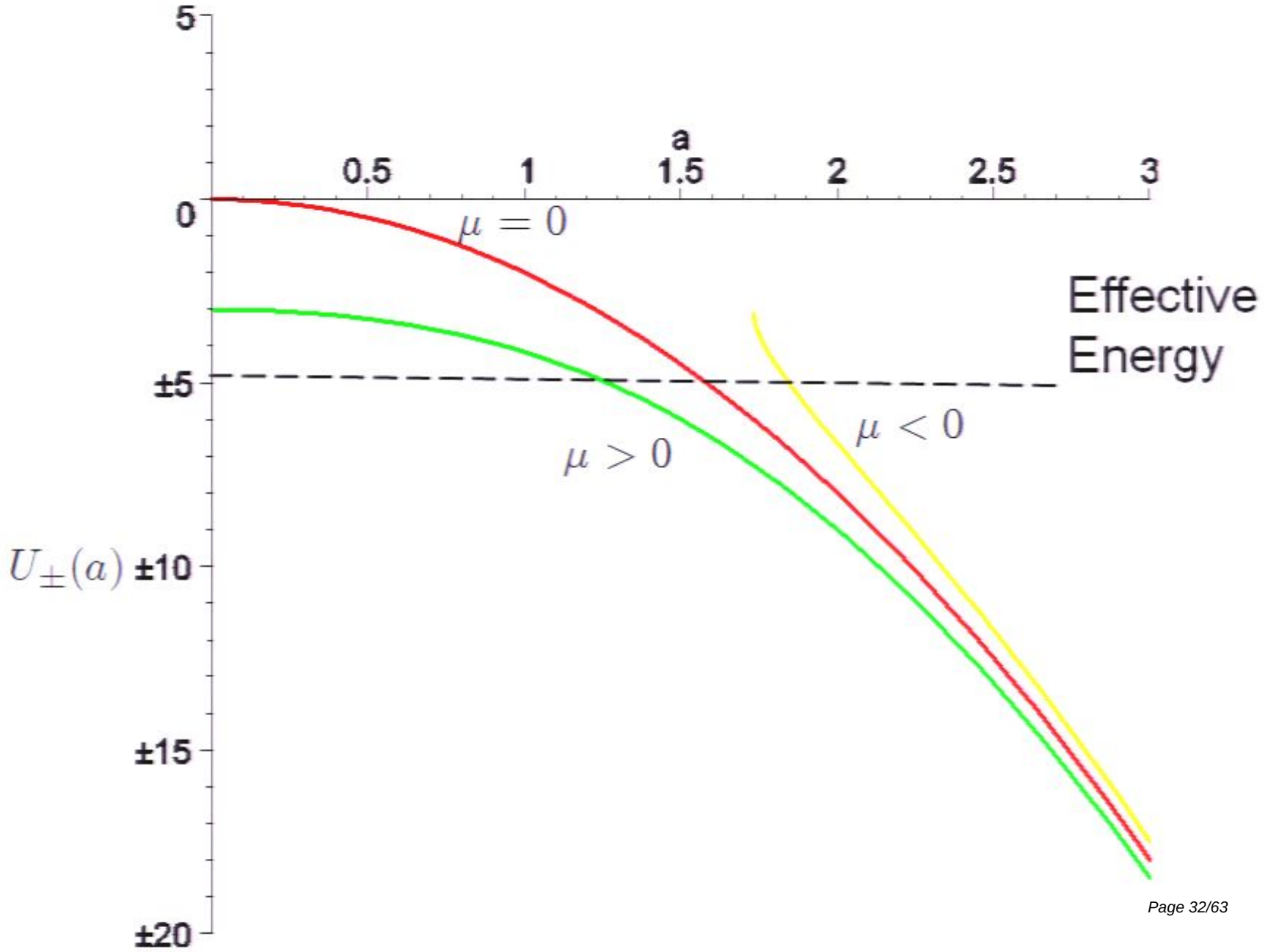
Israel junction conditions: $\dot{a}^2 + U(a) = -1$

$$U(a) = -\frac{H_0^2}{2} a^2 \left(1 + \sqrt{1 + \frac{4\mu}{H_0^2} \frac{1}{a^4}}\right)$$

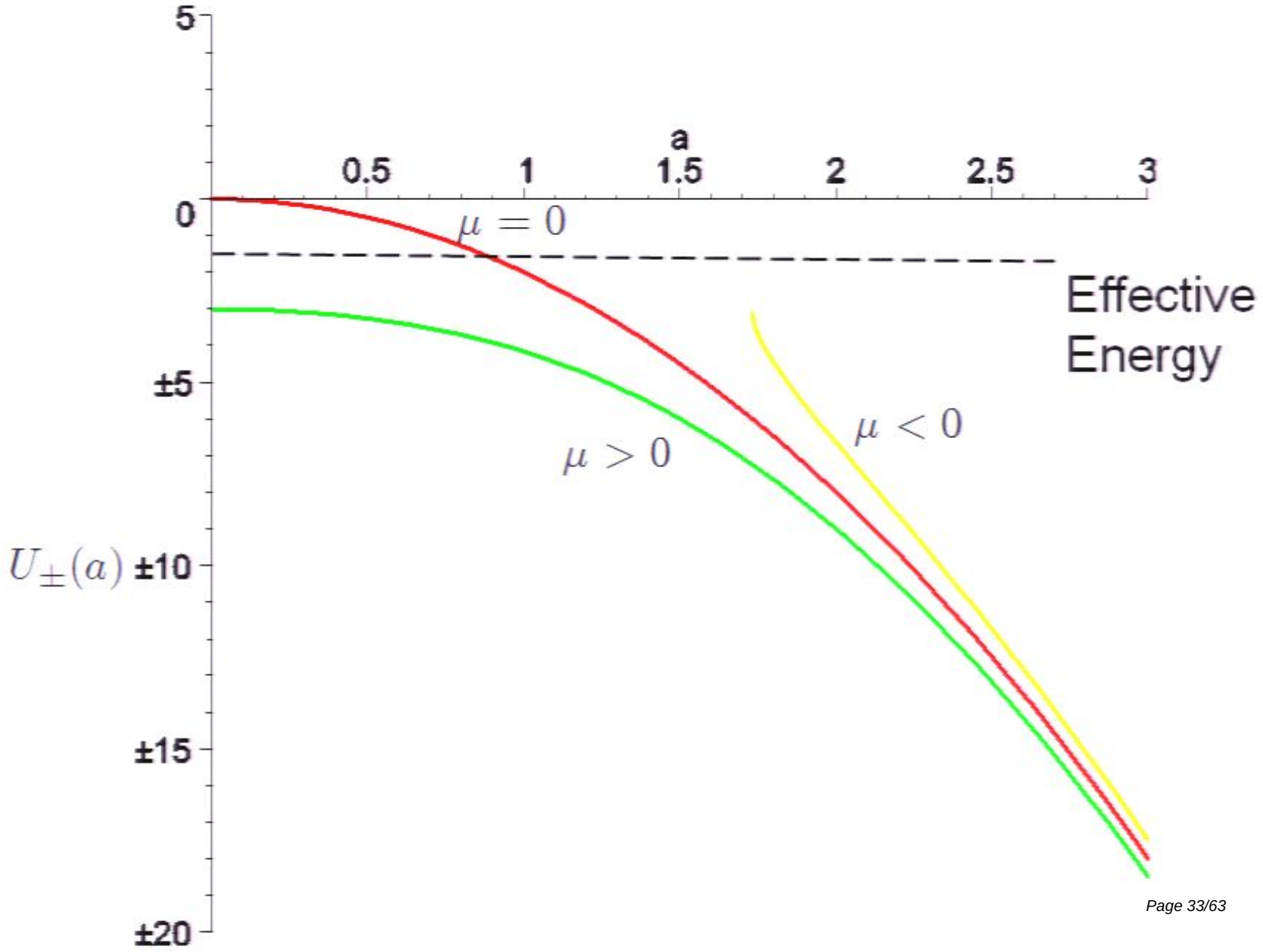
Effective Potential:



Effective Potential:

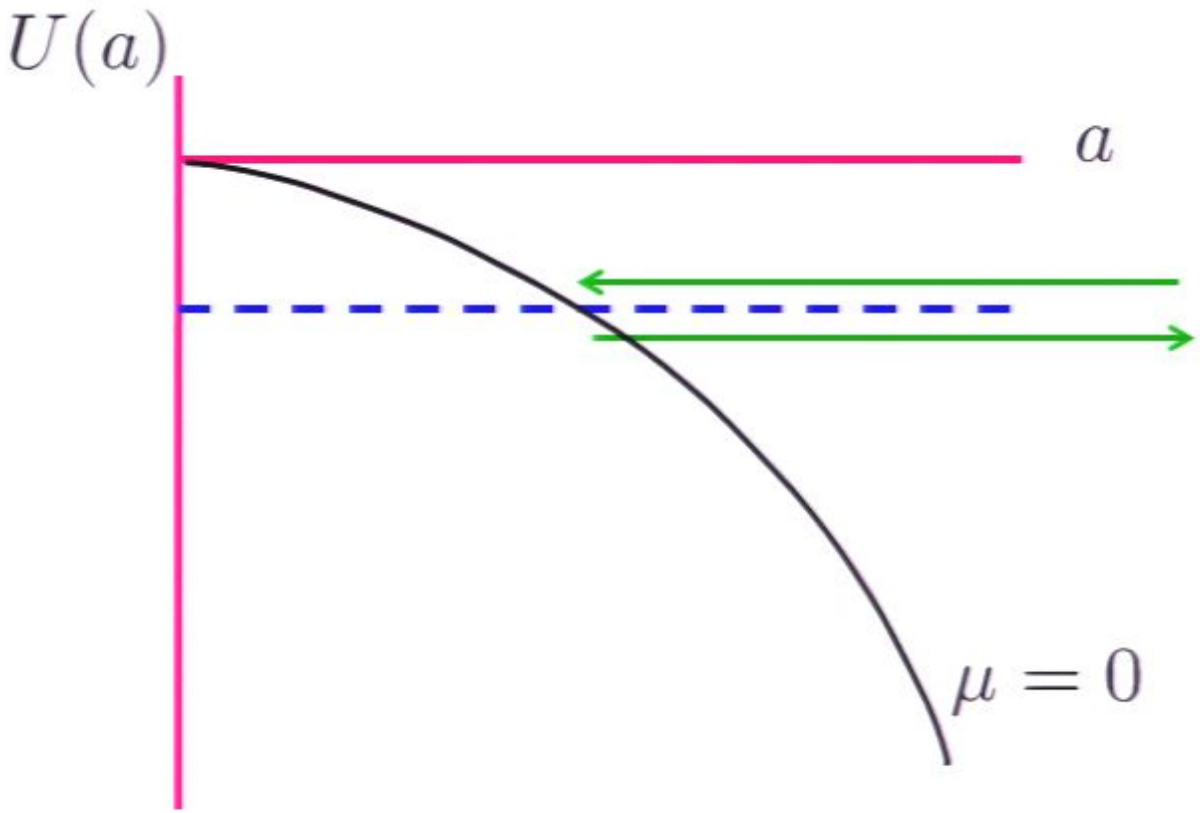


Effective Potential:



Classical point particle: $\dot{a}^2 + U(a) = -1$

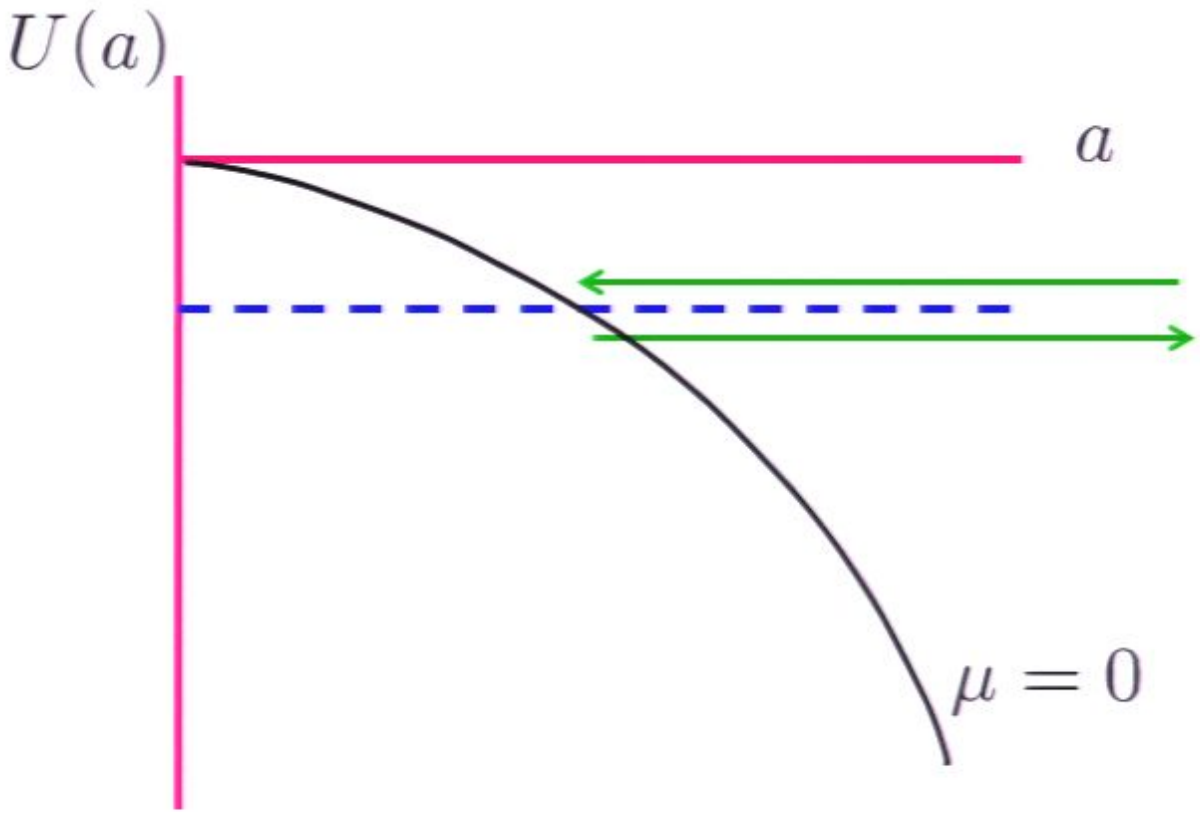
$$U(a) = -\frac{H_0^2}{2} a^2 \left(1 + \sqrt{1 + \frac{4\mu}{H_0^2} \frac{1}{a^4}} \right)$$



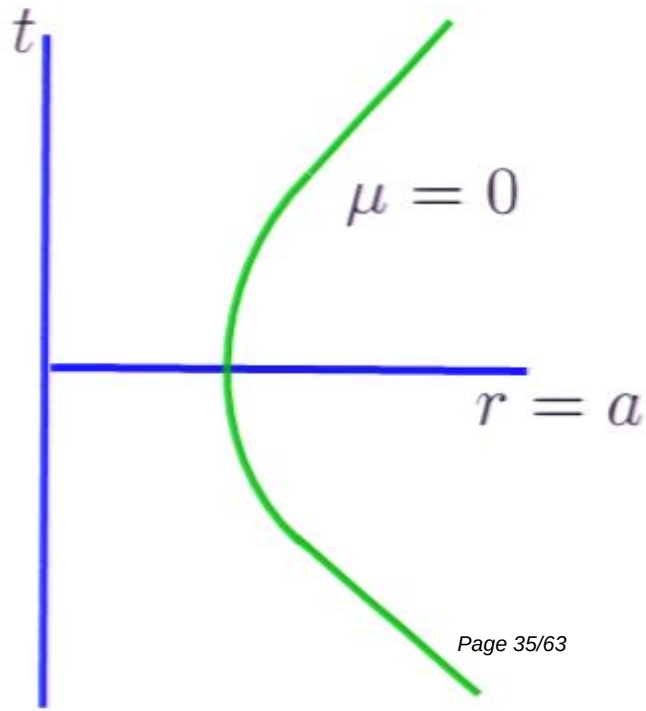
Open Trajectory
=
Bouncing Cosmology

Classical point particle: $\dot{a}^2 + U(a) = -1$

$$U(a) = -\frac{H_0^2}{2} a^2 \left(1 + \sqrt{1 + \frac{4\mu}{H_0^2}\frac{1}{a^4}} \right)$$

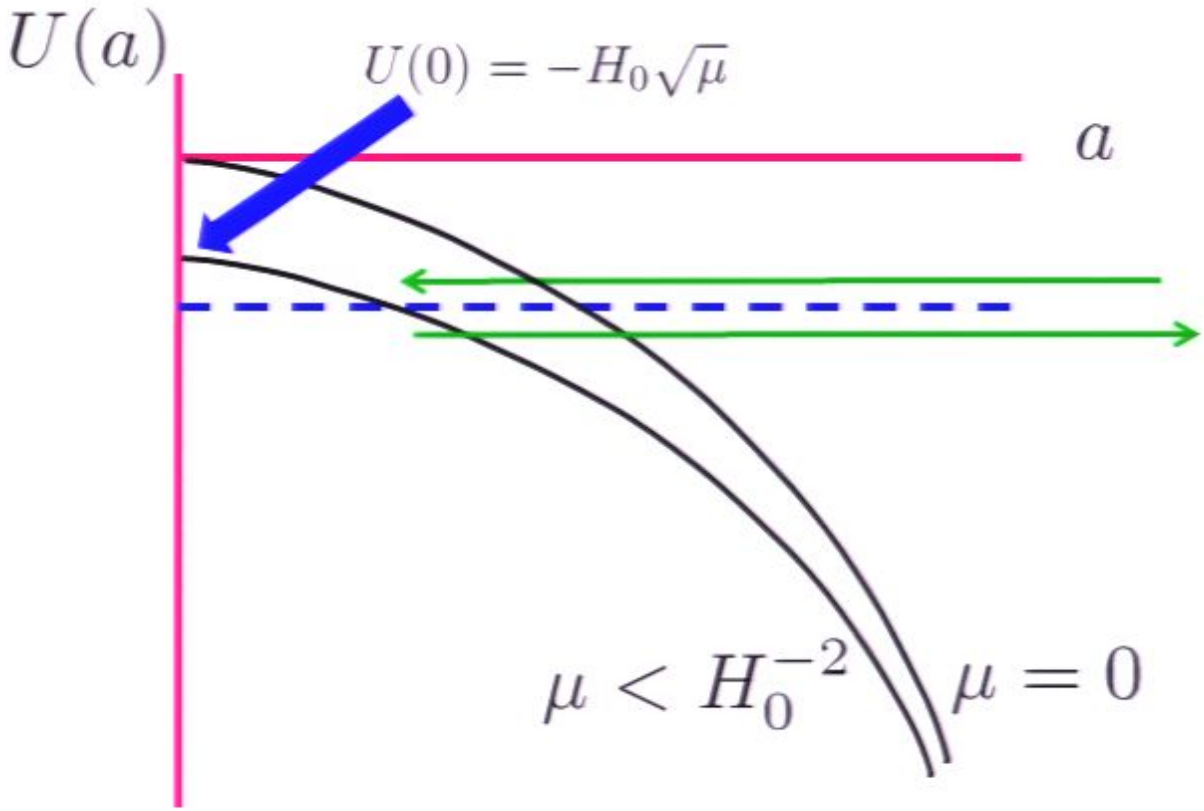


Open Trajectory
=
Bouncing Cosmology

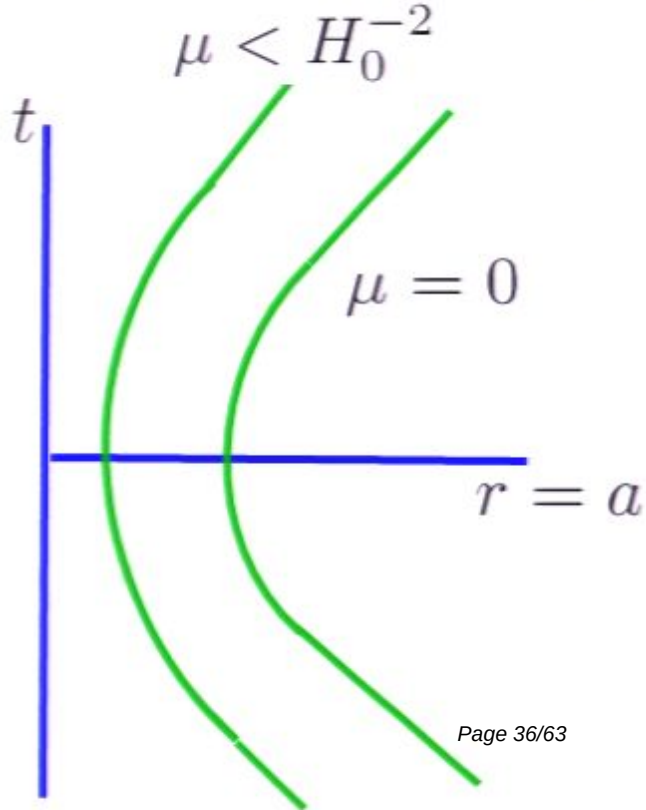


Classical point particle: $\dot{a}^2 + U(a) = -1$

$$U(a) = -\frac{H_0^2}{2} a^2 \left(1 + \sqrt{1 + \frac{4\mu}{H_0^2} \frac{1}{a^4}} \right)$$

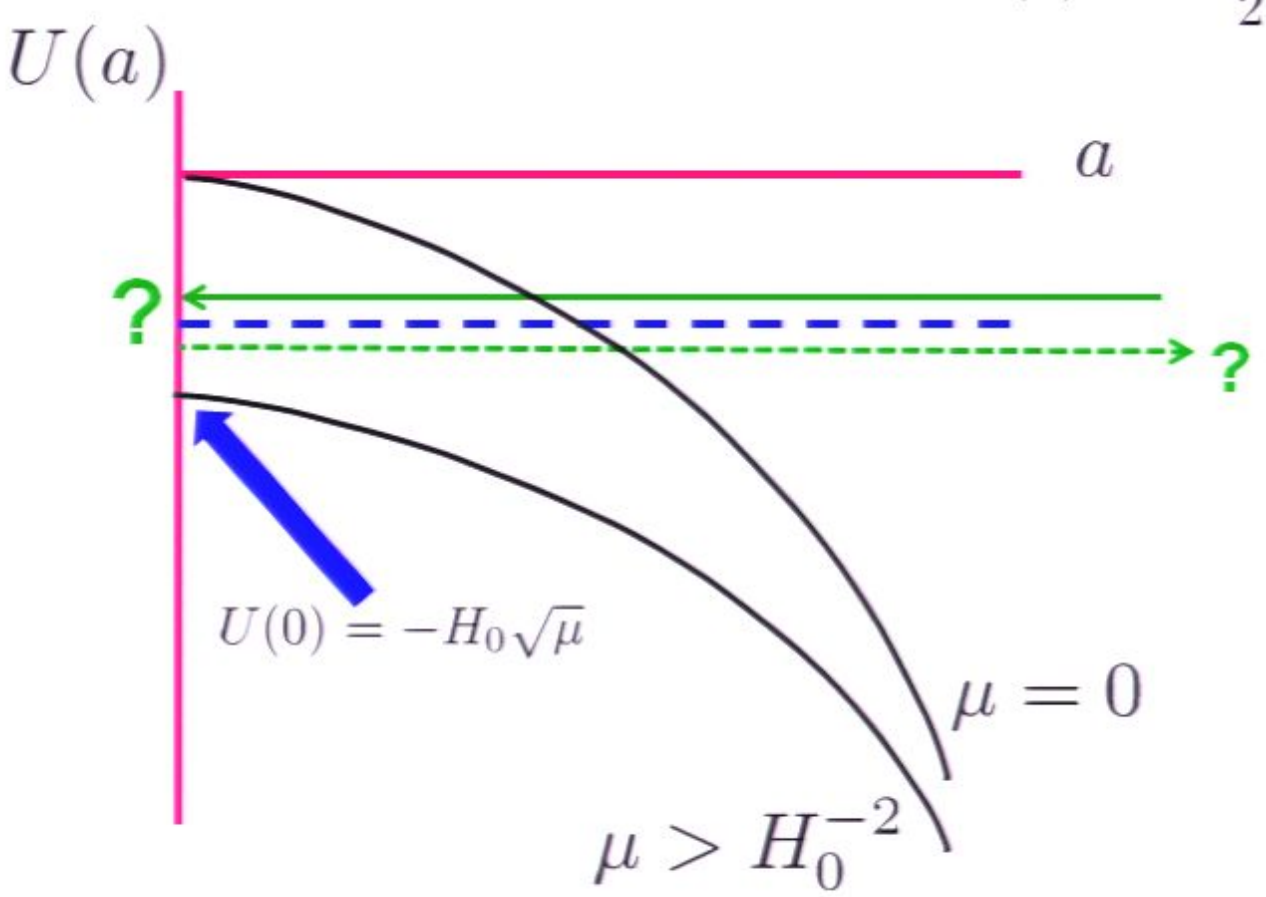


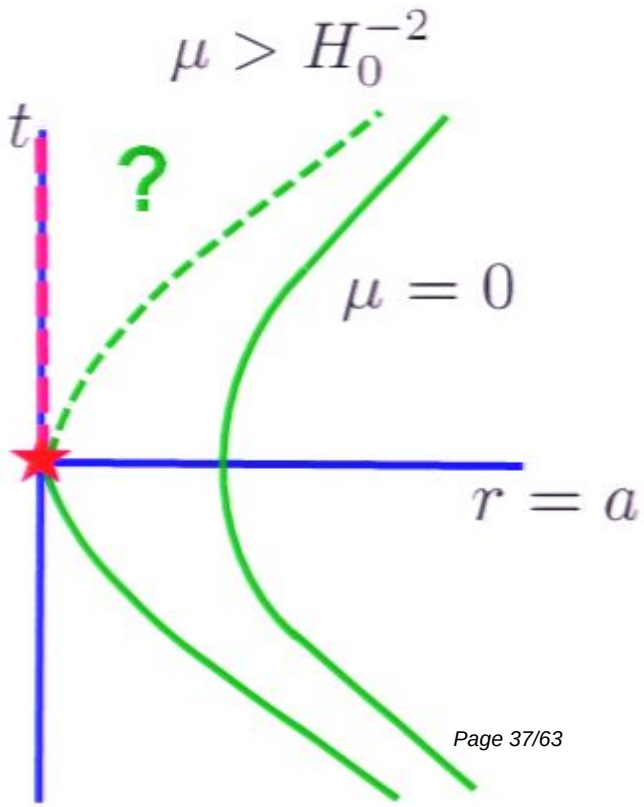
Open Trajectory
=
Bouncing Cosmology



Classical point particle: $\dot{a}^2 + U(a) = -1$

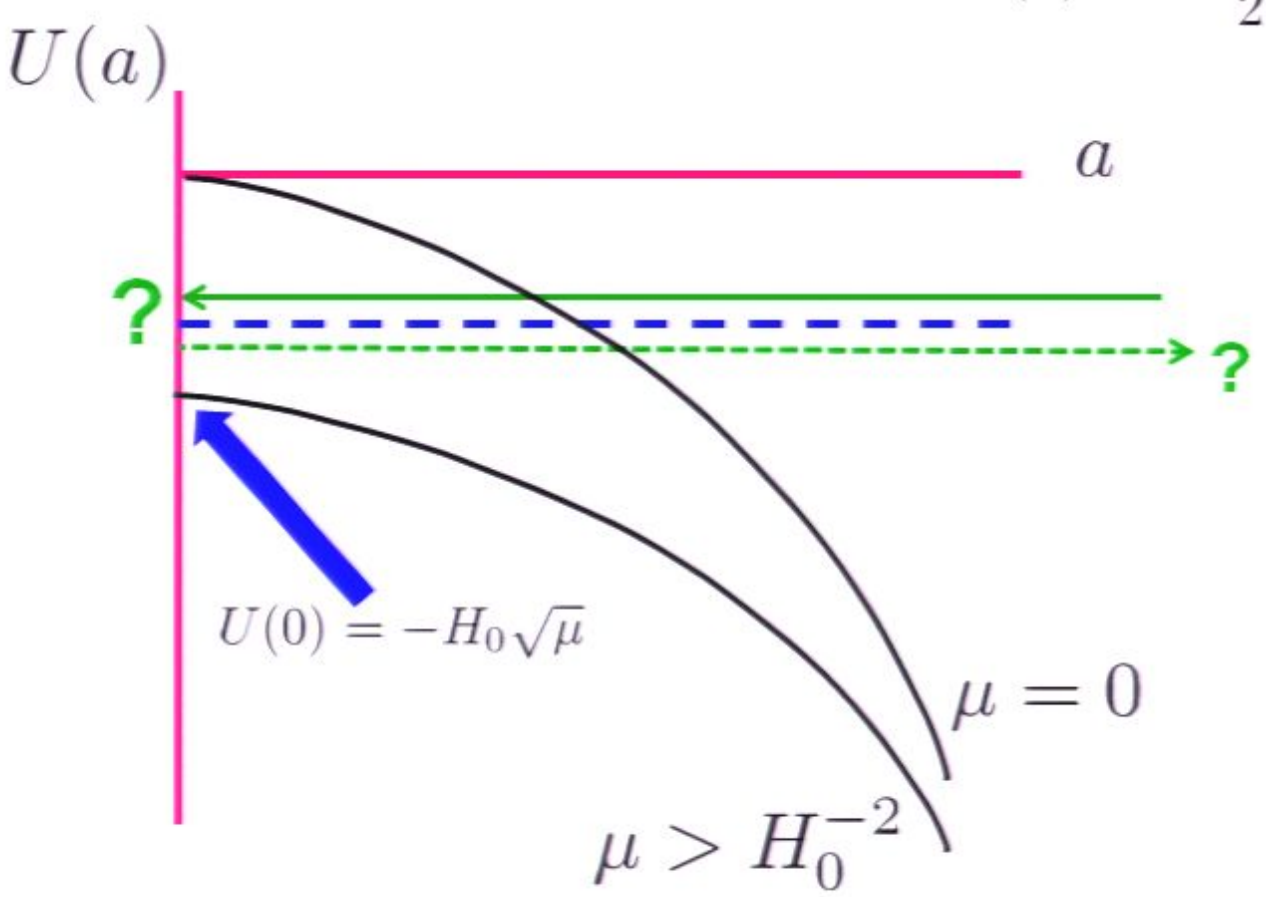
$$U(a) = -\frac{H_0^2}{2} a^2 \left(1 + \sqrt{1 + \frac{4\mu}{H_0^2} \frac{1}{a^4}} \right)$$

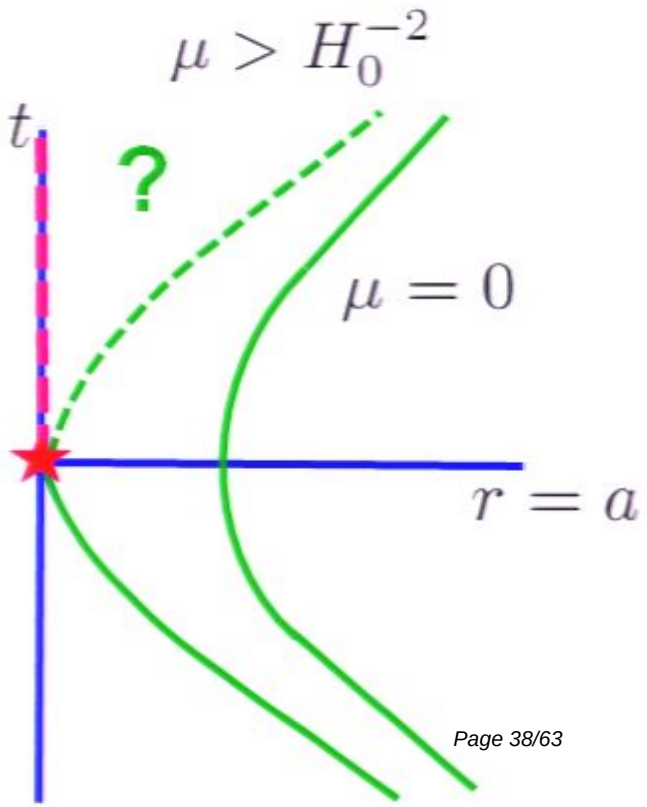




Classical point particle: $\dot{a}^2 + U(a) = -1$

$$U(a) = -\frac{H_0^2}{2} a^2 \left(1 + \sqrt{1 + \frac{4\mu}{H_0^2}\frac{1}{a^4}} \right)$$

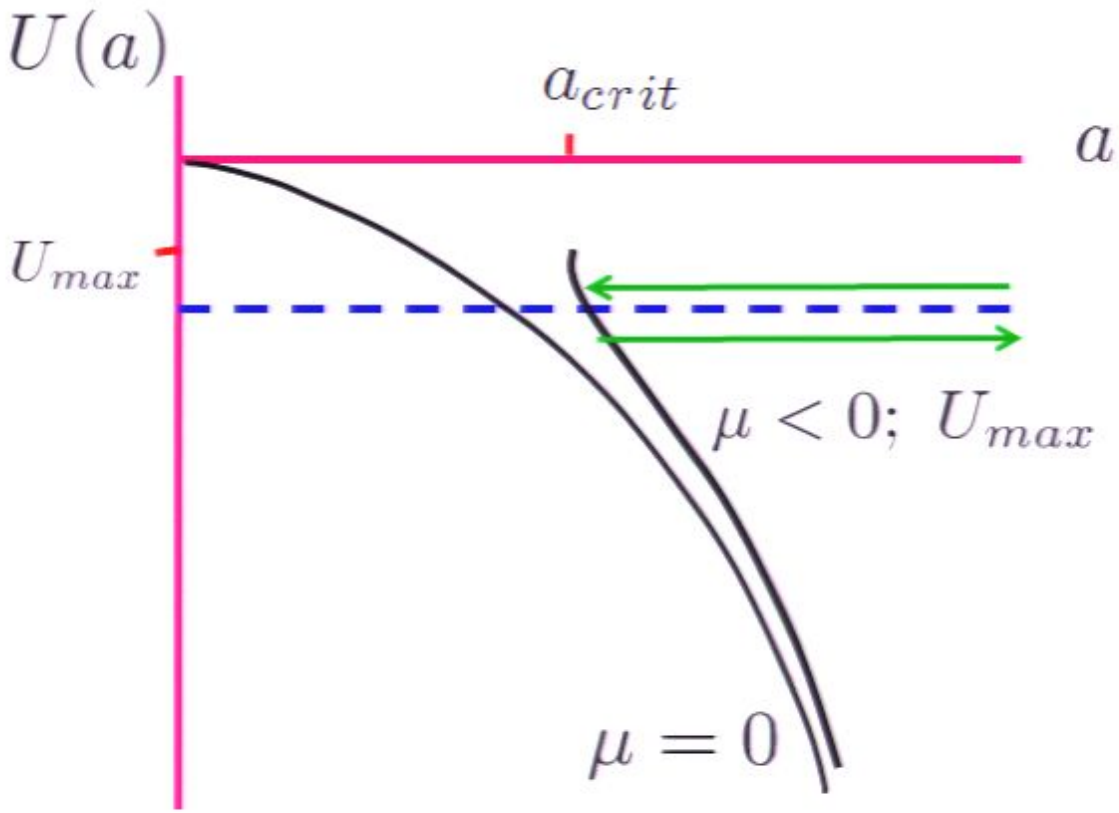




For large μ, solution singular but still have smooth initial data

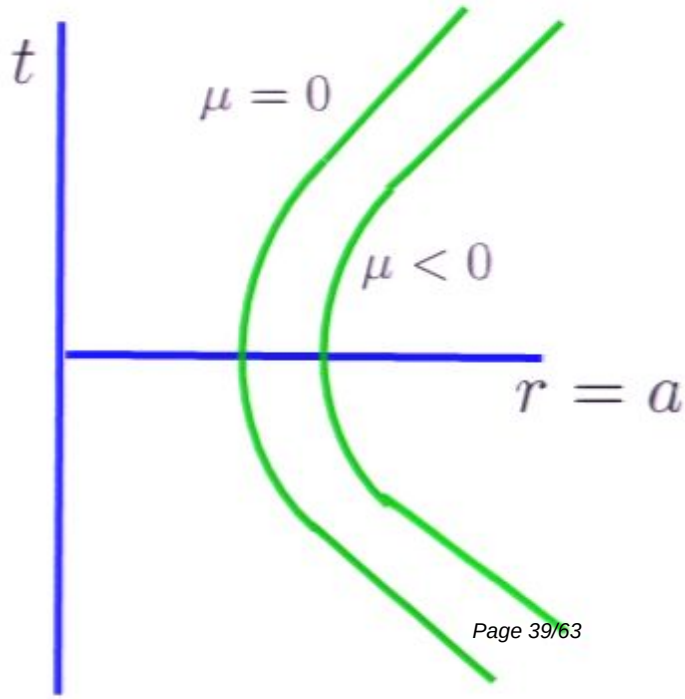
Aside: SA branch with μ<0 $(M > 0)$

$$\dot{a}^2 + U(a) = -1$$



$$a_{crit}^4 = \frac{4\mu}{H_0^2}$$

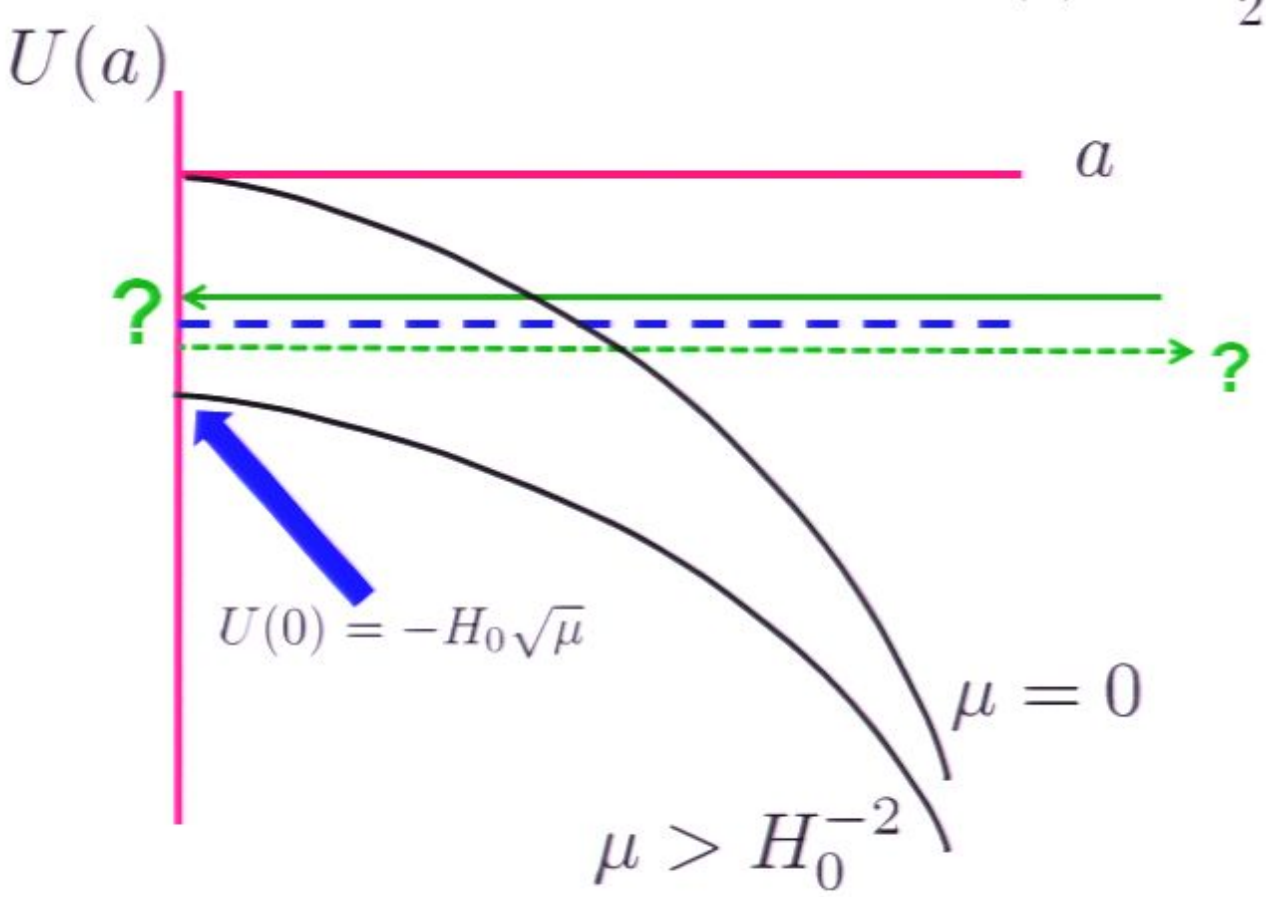
$$U_{max} = -H_0\,\mu^{1/2}$$

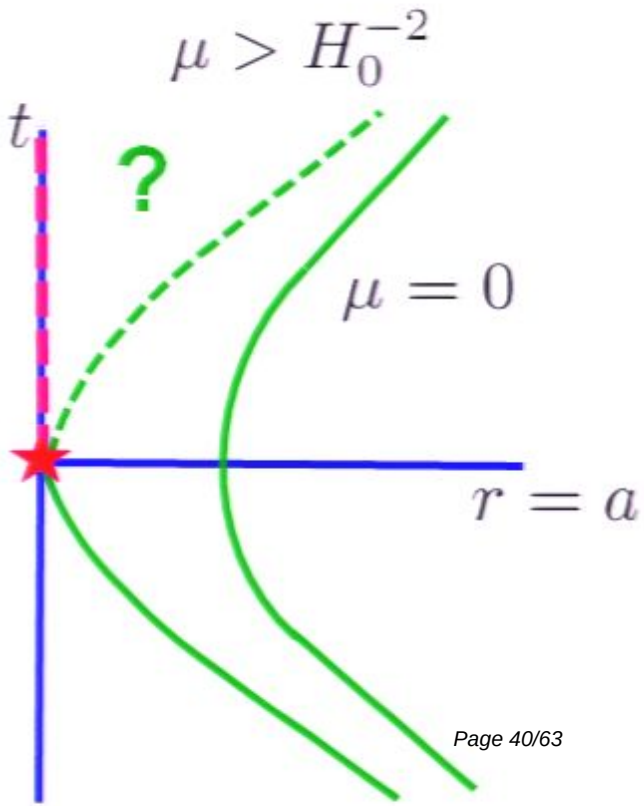


effect of μ<0 is repulsive

Classical point particle: $\dot{a}^2 + U(a) = -1$

$$U(a) = -\frac{H_0^2}{2} a^2 \left(1 + \sqrt{1 + \frac{4\mu}{H_0^2} \frac{1}{a^4}} \right)$$

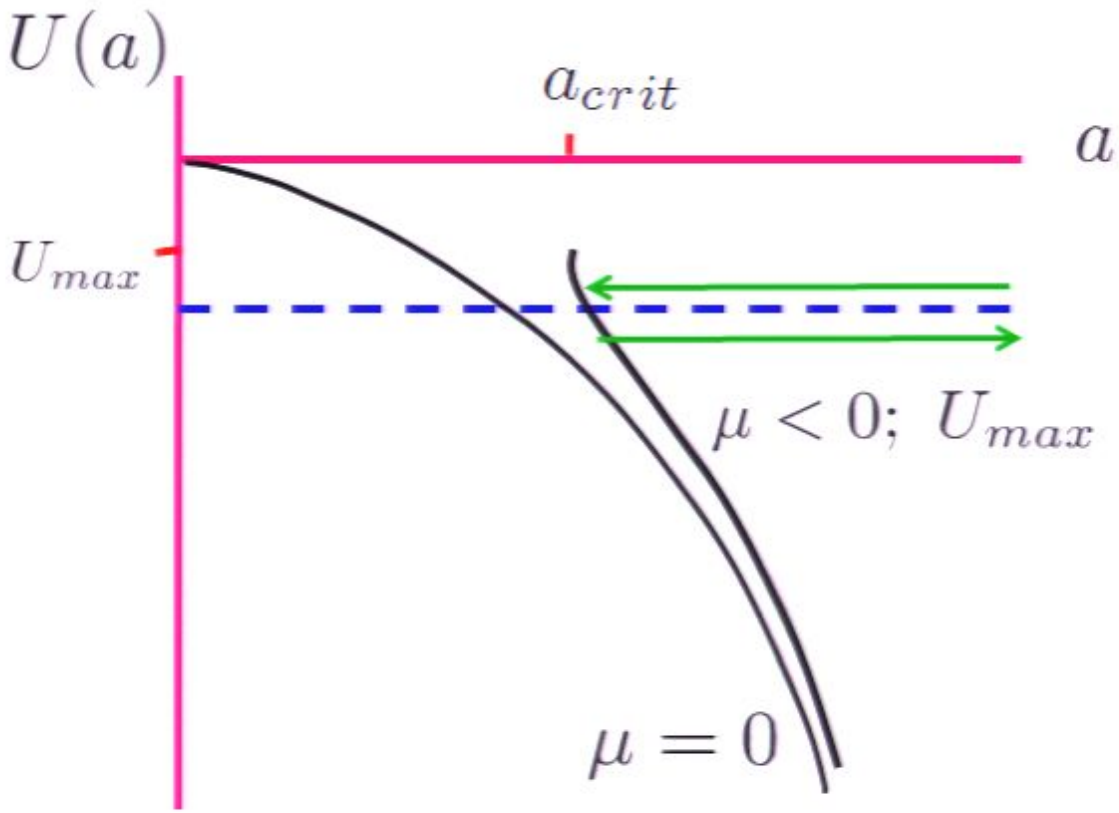




For large μ, solution singular but still have smooth initial data

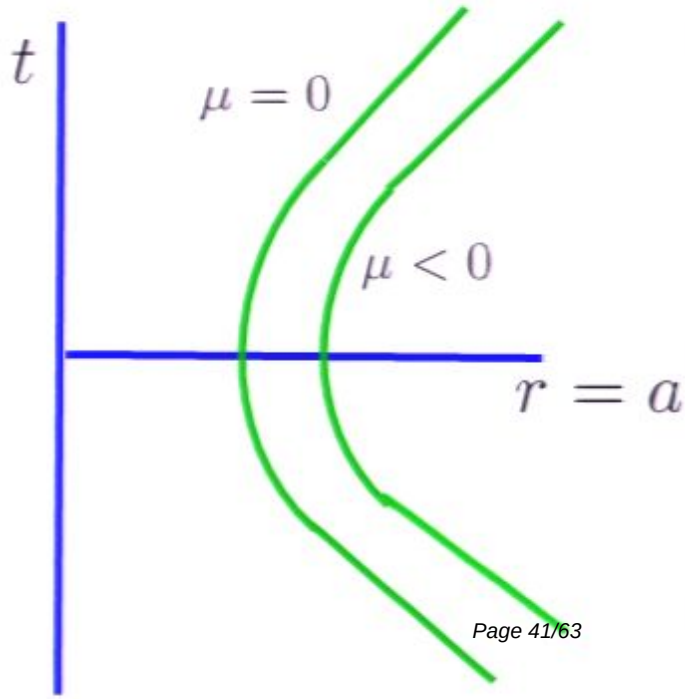
Aside: SA branch with μ<0 $(M > 0)$

$$\dot{a}^2 + U(a) = -1$$



$$a_{crit}^4 = \frac{4\mu}{H_0^2}$$

$$U_{max} = -H_0\,\mu^{1/2}$$



effect of μ<0 is repulsive

- spectrum of DGP is unbounded below!

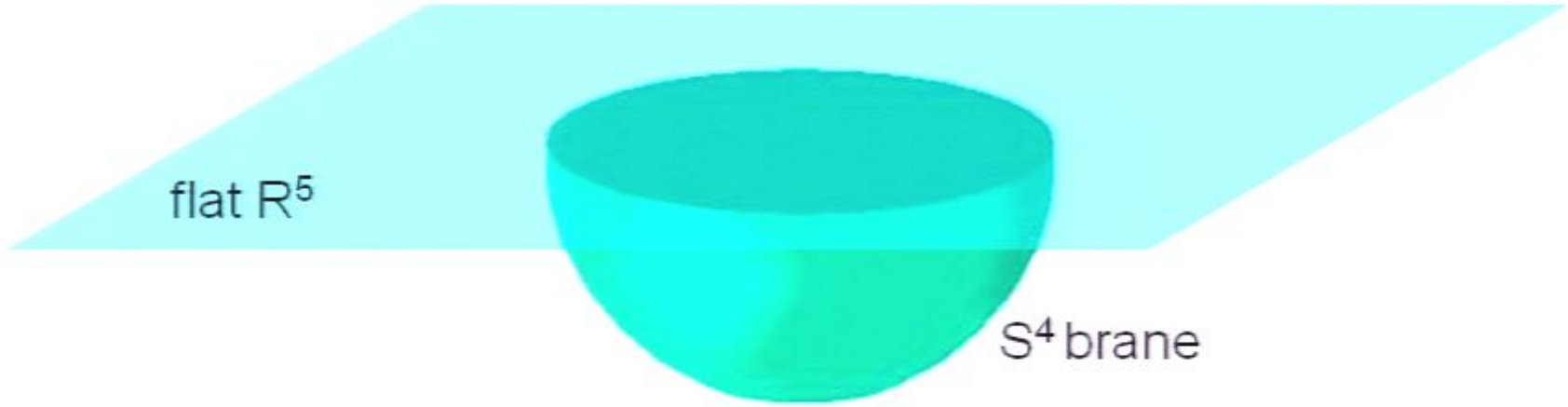
- many more general solutions with M<0

  → SA brane shields solution from bulk singularity

- expect theory unstable; no ground state

Tunneling (with M=0; so complementary to previous)

- Euclidean instanton describing appearance of SA brane



- tunneling probability $\propto \quad \exp\left(-\Delta S_E\right)$

$$\Delta S_E = S_{instanton} - S_{background}$$

Summary of 5d perspective:

1. SA branes are "wormholes"

2. Spectrum of DGP model is unbounded below

3. Spontaneous creation of SA branes is unsupressed

Summary of 5d perspective:

1. SA branes are "wormholes" (fixed by orbifold branes)

2. Spectrum of DGP model is unbounded below

3. Spontaneous creation of SA branes is unsupressed

Summary of 5d perspective:

1. SA branes are "wormholes" (fixed by orbifold branes)

2. Spectrum of DGP model is unbounded below

3. Spontaneous creation of SA branes is unsupressed

(Quantum effects strongly modify classical picture)

Summary of 5d perspective:

1. SA branes are "wormholes" (fixed by orbifold branes)

2. Spectrum of DGP model is unbounded below

3. Spontaneous creation of SA branes is unsupressed

(Quantum effects strongly modify classical picture)

DGP **model** is pathological!
Does **not** provide a consistent framework to, eg,
propose new astro/cosmo phenomenology

Summary of 5d perspective:

1. SA branes are "wormholes" (fixed by orbifold branes)

2. Spectrum of DGP model is unbounded below

3. Spontaneous creation of SA branes is unsupressed

(Quantum effects strongly modify classical picture)

DGP **model** is pathological!
Does **not** provide a consistent framework to, eg,
propose new astro/cosmo phenomenology

"MODEL" is no good!

Challenge for any UV completion

Summary of 5d perspective:

1. SA branes are "wormholes" (fixed by orbifold branes)

2. Spectrum of DGP model is unbounded below

3. Spontaneous creation of SA branes is unsupressed

(Quantum effects strongly modify classical picture)

DGP **model** is pathological!
Does **not** provide a consistent framework to, eg, propose new astro/cosmo phenomenology

"MODEL" is no good!

Challenge for any UV completion

SA branes are source of problem.
So can we get rid of them?

DGP Gravity v2.2:

consider effects of UV completion – higher dimension terms

as toy model, add: $\alpha / M_4^{2n-4} \int d^4x \, \mathcal{R}^n$

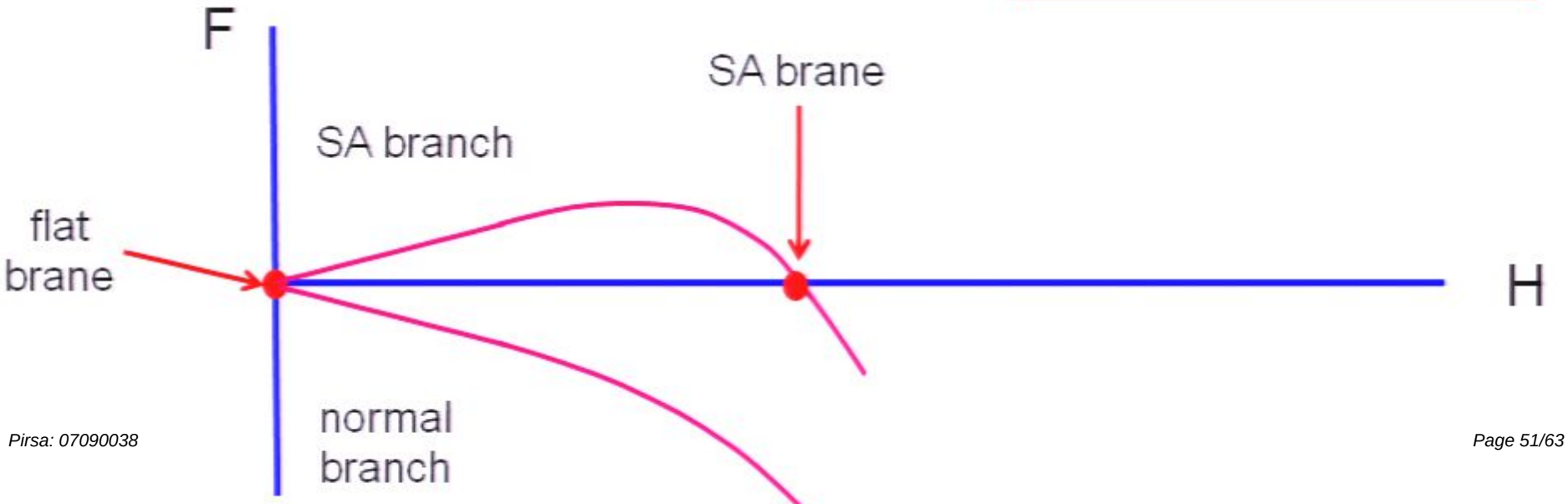
DGP Gravity v2.2:

consider effects of UV completion – higher dimension terms

as toy model, add: $\alpha/M_4^{2n-4}\int d^4x\,\mathcal{R}^n$

⟶ modify eom ⟶ look for deSitter cosmologies

$$0 = F_\pm(H) \simeq \pm M_5^3 H - M_4^2 H^2 - \alpha M_4^4 \left(\frac{H}{M_4}\right)^{2n}$$



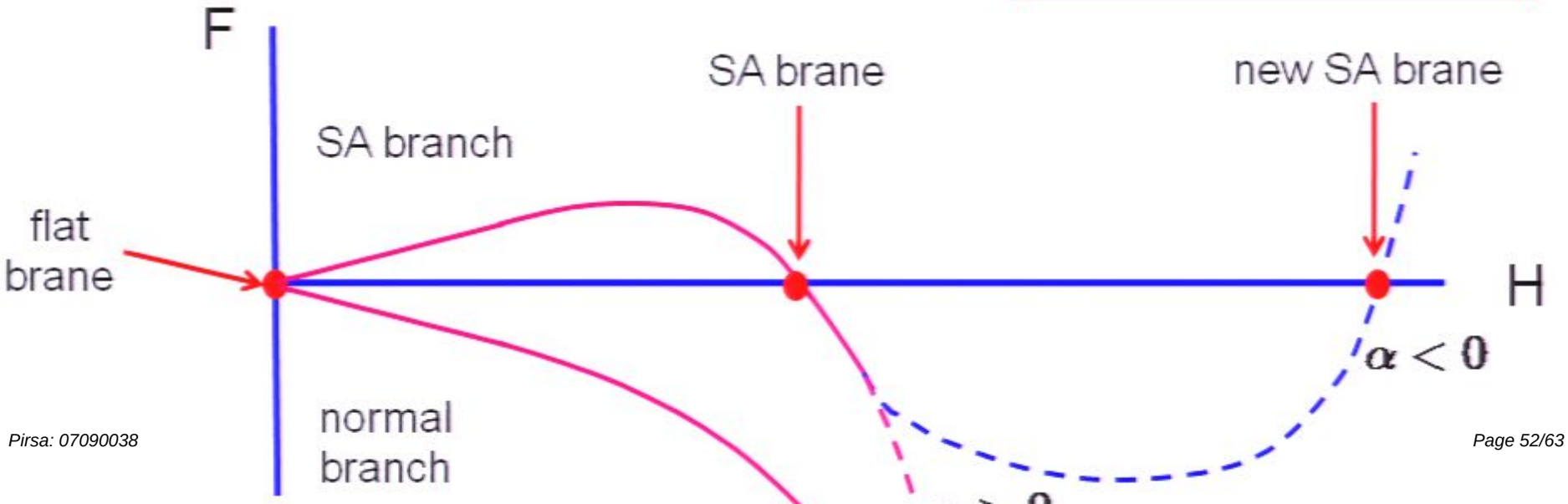
DGP Gravity v2.2:

consider effects of UV completion – higher dimension terms

as toy model, add: $\alpha / M_4^{2n-4} \int d^4x \, \mathcal{R}^n$

⟶ modify eom ⟶ look for deSitter cosmologies

$$0 = F_{\pm}(H) \simeq \pm M_5^3 H - M_4^2 H^2 - \alpha M_4^4 \left(\frac{H}{M_4} \right)^{2n}$$



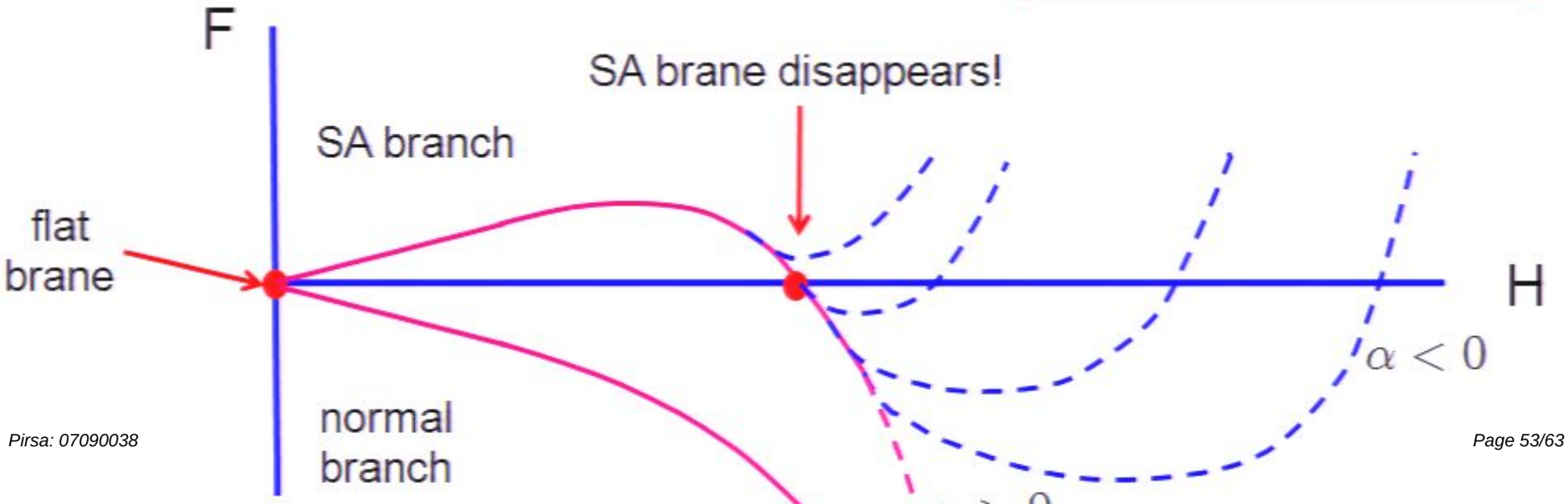
DGP Gravity v2.2:

consider effects of UV completion – higher dimension terms

as toy model, add: $\alpha/M_4^{2n-4}\int d^4x\,\mathcal{R}^n$

⟶ modify eom ⟶ look for deSitter cosmologies

$$0 = F_\pm(H) \simeq \pm M_5^3 H - M_4^2 H^2 - \alpha M_4^4 \left(\frac{H}{M_4}\right)^{2n}$$



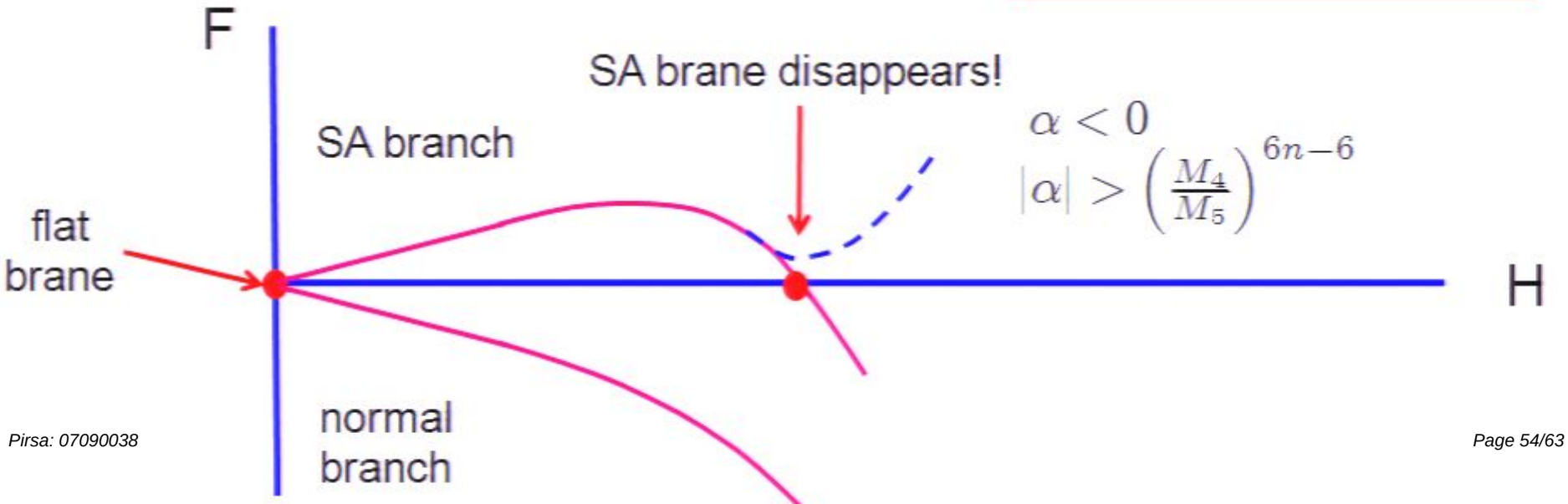
DGP Gravity v2.2:

consider effects of UV completion – higher dimension terms

as toy model, add: $\alpha/M_4^{2n-4}\int d^4x\,\mathcal{R}^n$

⟶ modify eom ⟶ look for deSitter cosmologies

$$0 = F_\pm(H) \simeq \pm M_5^3 H - M_4^2 H^2 \boxed{- \alpha M_4^4 \left(\frac{H}{M_4}\right)^{2n}}$$



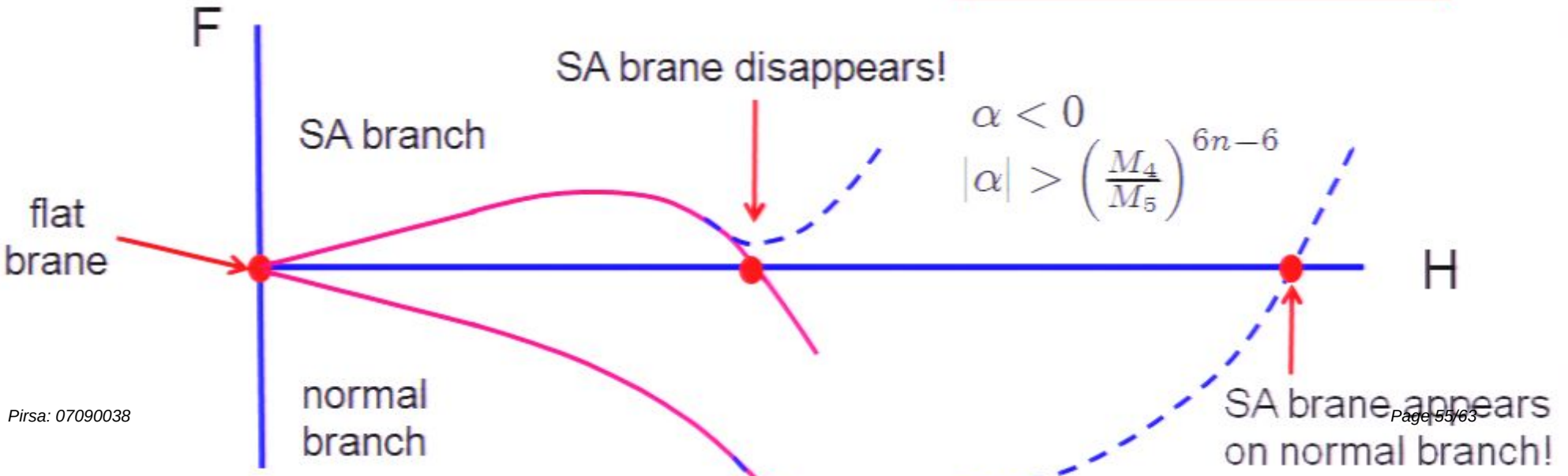
DGP Gravity v2.2:

consider effects of UV completion – higher dimension terms

as toy model, add: $\alpha/M_4^{2n-4}\int d^4x\,\mathcal{R}^n$

⟶ modify eom ⟶ look for deSitter cosmologies

$$0 = F_\pm(H) \simeq \pm M_5^3 H - M_4^2 H^2 \boxed{- \alpha M_4^4 \left(\frac{H}{M_4}\right)^{2n}}$$



DGP Gravity v2.2:

consider effects of UV completion – higher dimension terms

as toy model, add: $\alpha / M_4^{2n-4} \int d^4x \, \mathcal{R}^n$

$\longrightarrow$ with α sufficiently negative find new SA brane on normal branch – avoids previous pathologies

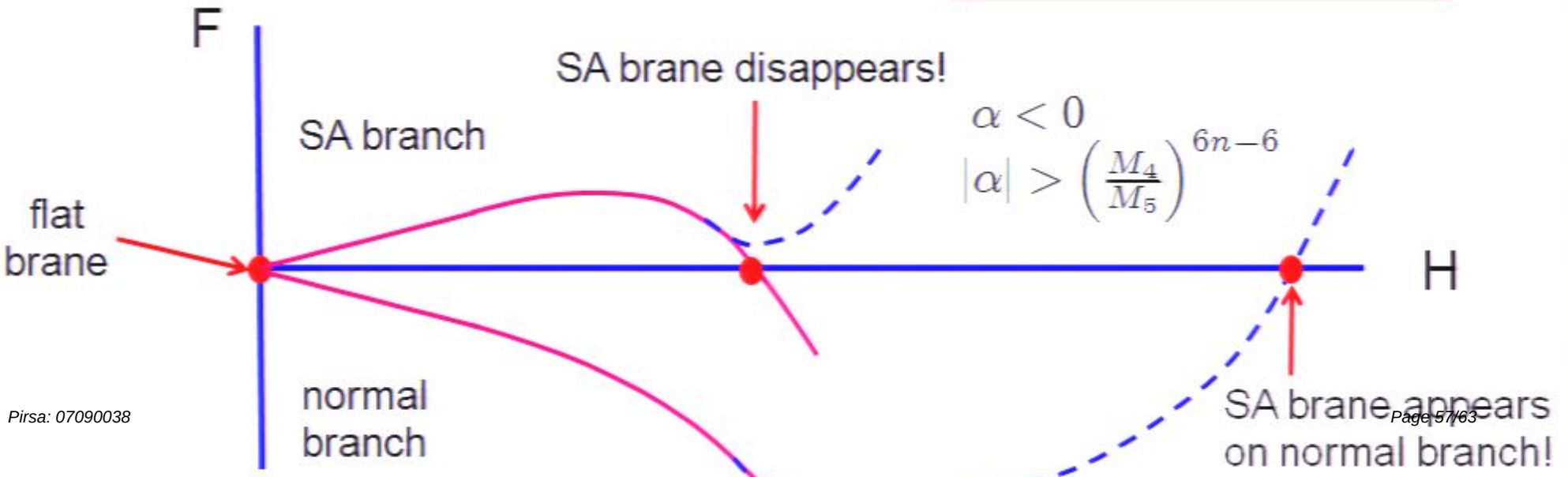
DGP Gravity v2.2:

consider effects of UV completion – higher dimension terms

as toy model, add: $\alpha/M_4^{2n-4}\int d^4x\,\mathcal{R}^n$

⟶ modify eom ⟶ look for deSitter cosmologies

$$0 = F_\pm(H) \simeq \pm M_5^3 H - M_4^2 H^2 \boxed{- \alpha M_4^4 \left(\frac{H}{M_4}\right)^{2n}}$$



DGP Gravity v2.2:

consider effects of UV completion – higher dimension terms

as toy model, add: $\alpha / M_4^{2n-4} \int d^4x \, \mathcal{R}^n$

$\longrightarrow$ with α sufficiently negative find new SA brane on normal branch – avoids previous pathologies

DGP Gravity v2.2:

consider effects of UV completion – higher dimension terms

as toy model, add: $\alpha / M_4^{2n-4} \int d^4x \, \mathcal{R}^n$

→ with α sufficiently negative find new SA brane on normal branch – avoids previous pathologies

interesting for phenomenology or UV junk??

- higher derivatives, new solutions, ghosts, ...

DGP Gravity v2.2:

consider effects of UV completion – higher dimension terms

as toy model, add: $\alpha / M_4^{2n-4} \int d^4x \, \mathcal{R}^n$

⟶ with α sufficiently negative find new SA brane on normal branch – avoids previous pathologies

interesting for phenomenology or UV junk??

- higher derivatives, new solutions, ghosts, ...

perhaps find more control with dimension-two operators?

$$M_4^2 \int d^4x \, (\alpha \, K_{\mu\nu} K^{\mu\nu} + \beta \, K^2)$$

(Gabadadze)

DGP Gravity v2.2:

consider effects of UV completion – higher dimension terms

as toy model, add: $\alpha / M_4^{2n-4} \int d^4x \, \mathcal{R}^n$

→ with α sufficiently negative find new SA brane on normal branch – avoids previous pathologies

interesting for phenomenology or UV junk??

- higher derivatives, new solutions, ghosts, ...

DGP Gravity v2.2:

consider effects of UV completion – higher dimension terms

as toy model, add: $\alpha / M_4^{2n-4} \int d^4x \, \mathcal{R}^n$

⟶ with α sufficiently negative find new SA brane on normal branch – avoids previous pathologies

interesting for phenomenology or UV junk??

- higher derivatives, new solutions, ghosts, ...

perhaps find more control with dimension-two operators?

$$M_4^2 \int d^4x \, (\alpha \, K_{\mu\nu} K^{\mu\nu} + \beta \, K^2)$$

(Gabadadze)

Summary of 5d perspective:

1. SA branes are "wormholes" (fixed by orbifold branes)

2. Spectrum of DGP model is unbounded below

3. Spontaneous creation of SA branes is unsupressed

(Quantum effects strongly modify classical picture)

DGP **model** is pathological!
Does **not** provide a consistent framework to, eg,
new propose astro/cosmo phenomenology

"MODEL" is no good!

Challenge for any UV completion

Techniques used here provide simple diagnostic for other models